An Overview of the Physical and Chemical Limnology of the Experimental Ponds Area, Central Newfoundland, 1977-82

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October 1984

Canadian Technical Report of Fisheries and Aquatic Sciences
No. 1320

85-1128/

Canadian Technical Report of Fisheries and Aquatic Sciences

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AN OVERVIEW OF THE PHYSICAL AND CHEMICAL LIMNOLOGY OF THE EXPERIMENTAL PONDS AREA, CENTRAL NEWFOUNDLAND, 1977-82

by

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This is the eighty-second Technical Report from
Fisheries Research Branch, St. John's, Newfoundland.

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Cat. No. Fs 97-6/1320 ISSN 0706-6457

Correct citation for this publication:

Ryan, P. M., and D. Wakeham. 1984. An overview of the physical and chemical limnology of the Experimental Ponds Area, central Newfoundland, 1977-82. Can. Tech. Rep. Fish. Aquat. Sci. 1320: v + 54 p.

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ABSTRACT

Ryan, P. M., and D. Wakeham. 1984. An overview of the physical and chemical limnology of the Experimental Ponds Area, central Newfoundland, 1977-82. Can. Tech. Rep. Fish. Aquat. Sci. 1320: v + 54 p.

Physical and chemical limnological data were obtained from three small, brown-water lakes and their tributary streams in the Experimental Ponds Area at the headwaters of the Gander River system, central Newfoundland. Water sampling from near the end of May to early October at approximate two week intervals started on Spruce Pond and its tributaries in 1977. A second lake upstream, Headwater Pond, and its tributaries were similarly monitored since 1979. Some winter samples and occasional samples from downstream Little Gull Lake were obtained since 1978. Headwater Pond is a two basin lake of 76.1 ha with a mean depth of 1.1 m and a flushing rate of about 6.2 times yr^{-1}. Spruce Pond is 36.5 ha with a mean depth of 1.0 m and a flushing rate of about 49.7 times yr^{-1}. Little Gull Lake, 306.5 ha with a mean depth of 1.7 m, flushes about 11.0 times yr^{-1}. Maximum recorded ice thickness was 61 cm and average weekly mean mid-day lake temperatures from May to October each year ranged from 10.6 to 15.1°C. May to October flow in Spruce Pond's outlet to Little Gull Lake ranged from 0.00 to 1.76 m^3sec^{-1}. Annual and seasonal variations in water quality are described in the report. Overall, the water quality of the oligotrophic waters of the Experimental Ponds Area is typical of Newfoundland's freshwaters with average turbidity = 1.4 J.T.U., pH = 6.3, conductance = 34.3 $\mu S\ cm^{-1}$, chloride = 5.9 ppm, total hardness = 11 ppm, calcium = 2.8 ppm, and total alkalinity = 4.3 ppm. Average total phosphorus concentrations were less than 10 mg Pm^{-3} and the mean ratio of available nitrogen to available phosphorus was 10.8. Data obtained from the Experimental Ponds Area may serve as comparative data for the recognition of environmental change in the Experimental Ponds Area and elsewhere.

RÉSUMÉ

Ryan, P. M., and D. Wakeham. 1984. An overview of the physical and chemical limnology of the Experimental Ponds Area, central Newfoundland, 1977-82. Can. Tech. Rep. Fish. Aquat. Sci. 1320: v + 54 p.

Les chercheurs ont recueilli des données limnologiques sur la morphologie et la chimie de trois petits lacs à eau brune et leurs tributaires, situés dans la Zone des étangs expérimentaux à la tête du système de la rivière Gander, au centre de Terre-Neuve. L'échantillonnage de l'eau, effectué environ toutes les deux semaines de la fin mai au début d'octobre, a débuté dans l'étang Spruce et ses tributaires en 1977. Un second lac en amont, l'étang Headwater, a pareillement été étudié avec ses tributaires à partir de 1979. Un certain nombre d'échantillons ont été recueillis en hiver et, à l'occasion, à d'autres moments de l'année, dans le lac Little Gull en aval, à compter de 1978. L'étang Headwater est un lac à deux bassins qui a une superficie de 76,1 ha, une profondeur moyenne de 1,1 m et un taux de renouvellement des eaux de 6,2 fois par année. L'étang Spruce couvre 36,5 ha à une profondeur moyenne de

1,0 m; son taux de renouvellement se chiffre à environ 49,7 fois par année. Le lac Little Gull a une superficie et une profondeur moyenne de 306,5 ha et de 1,7 m respectivement et il se renouvelle environ 11 fois par année. L'épaisseur maximale de la glace s'élève à 61 cm et la température moyenne hebdomadaire de l'eau à midi, entre mai et octobre, variait de 10,6 à 15,1°C chaque année. Le débit dans l'émissaire entre l'étang Spruce et le lac Little Gull allait de 0,00 à 1,76 m^3 sec^{-1} entre mai et octobre. Une description des variations annuelles et saisonnières de la qualité de l'eau se retrouve dans le rapport. En général, la qualité des eaux oligotrophes de la Zone des étangs expérimentaux est typique des eaux douces de Terre-Neuve: la turbidité moyenne = 1,4JTU, le pH = 6,3, la conductance = 34,3 uS cm^{-1}, le chlorure = 5,9 ppm, la dureté totale = 11 ppm, la calcium = 2,8 ppm et l'alcalinité totale = 4,3 ppm. Les concentrations moyennes de phosphore total étaient inférieures à 10 mg Pm^{-3} et le rapport moyen entre l'azote disponible et le phosphore disponible s'élevait à 10,8. Les données recueillies dans la Zone d'étangs expérimentaux pourront servir pour une comparaison en vue de reconnaître des changements environnementaux dans cette zone et ailleurs.

INTRODUCTION AND BACKGROUND

PURPOSES OF THE STUDY

This report is an overview of the physical and chemical limnology of the Experimental Ponds Area, central Newfoundland. Physical and chemical data have been obtained from the Experimental Ponds Area for the purposes of:

- documenting natural variation in the Area prior to a possible experimental manipulation of part or all of the Area;
- documenting natural variation in the freshwaters of Newfoundland; and
- predicting the abundance of life forms in Newfoundland's fresh waters.

It is intended that this report and the data upon which it is based will serve as a foundation for monitoring long-term changes in the Experimental Ponds Area, assist in the interpretation of biological data collected from the Area, and assist in the interpretation of data collected over short time periods elsewhere.

THE EXPERIMENTAL PONDS AREA

The Experimental Ponds Area includes three small lakes and their tributary streams at the headwaters of the Gander River system. The Gander River system is the largest river system of insular Newfoundland in which the upstream migration of anadromous fishes is not prevented by obstructions (Murray and Harmon 1969). The three lakes[1] are, from south to north, and upstream to downstream, Headwater Pond (48°16'51"N, 55°29'39"W), Spruce Pond (48°19'40"N, 55°28'24"W), and Little Gull Lake (48°21'50"N, 55°29'38"W) (Fig. 1).

Headwater and Spruce ponds and their tributaries have been the most intensively studied. Headwater Pond is fed by three intermittent rivulets of little or no flow and an inlet draining a series of smaller ponds to the west. The intermittent inlets at the northeast and northwest corners of Headwater Pond each drain a smaller pond. The intermittent rivulet at Headwater Pond's southwest corner is periodically fed by bog drainage. Headwater Pond's outlet flows into Spruce Pond, 3.5 km to the north. Spruce Pond has its major inlet from Headwater Pond, a minor inlet draining a series of small ponds, and an outlet flowing into Little Gull Lake, 3.3 km to the north. Little Gull Lake, with five inlets, drains into Little Gull River and on downstream to the Northwest Gander River, into Gander Lake, on down the Gander River and into the Atlantic Ocean.

The surface geology and climate in Newfoundland have been summarized by Murray and Harmon (1969). In the drainage basin of the Experimental Ponds Area, a forest predominantly of black spruce (Picea mariana) with some balsam fir (Abies balsamea) on podzol soils and Sphagnum bogs cover sedimentary and volcanic rocks of Ordovician, Silurian, and Devonian age. Average annual

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[1]Commonly, small Newfoundland lakes are referred to as ponds. See Wetzel (1975) for terminology.

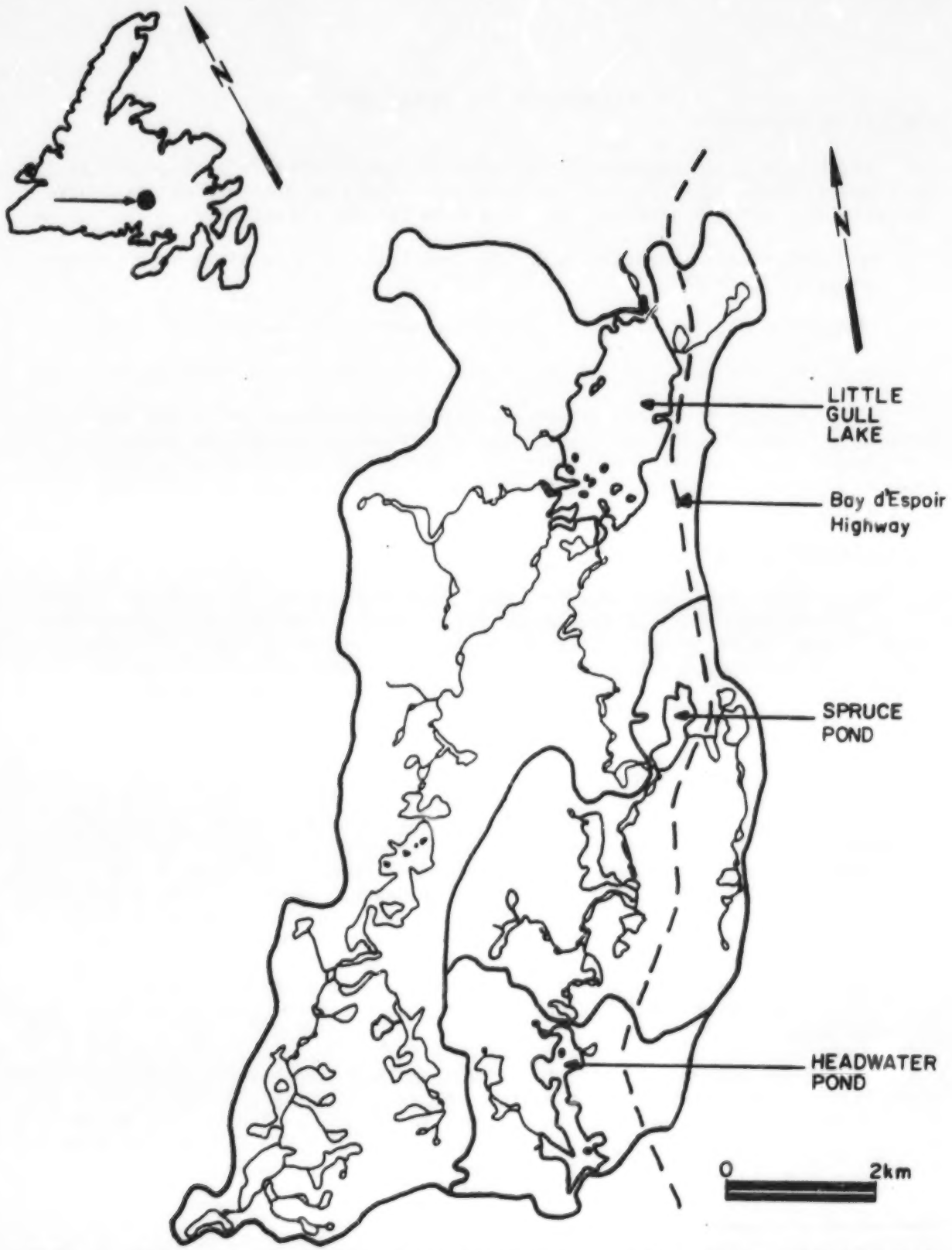

Fig. 1. Locations and catchment basins of the study lakes in the Experimental Ponds Area, central Newfoundland.

precipitation is about 90 cm and surface waters in the Area are typically ice-covered from December to April. The average length of the growing season (mean daily temperature greater than 6°C) is about 160 days.

HISTORY OF THE AREA

The Experimental Ponds Area was last glaciated about 11 - 12 thousand years ago during the Wisconsin glaciation (Rogerson 1983). The Area was crossed by W. E. Cormack in 1822 during his trans-Newfoundland expedition in search of Beothuck Indians (Thoms 1967). With the construction of various phases of the Bay D'Espoir highway in the late 1960's (Hobbs 1967), the wilderness area became readily accessible and two small cottages were constructed on Spruce Pond. This study was started in 1977. Eleven thousand cords of insect-damaged and overmature spruce and fir were logged in the Area from the winter of 1979-80 to the winter of 1980-81 (Ed Blackmore[2], personal communication). Nearly all of this wood was in the catchment basins of Headwater and Spruce ponds, on the east side of the lakes (Fig. 2). In April of 1981, the waters upstream of Spruce Pond's outlet at Little Gull Lake were closed to angling by order of the Department of Fisheries and Oceans. In the summer of 1982, approximately 11% of the drainage basin of Headwater Pond, about 0.8 km from the lake on the east side of the Bay D'Espoir highway, was clearcut by the Province of Newfoundland's Department of Forest Resources and Lands (Fig. 2). This clearcutting was done as part of an experiment to determine the effects of various forestry practices on forest regeneration (Ed Blackmore, personal communication).

CHRONOLOGY OF THE STUDY

Sampling of Spruce Pond and its major inlet and outlet was started in February of 1977, and continued from early June until early October, with water sampling at approximate two week intervals. In subsequent years, the monitoring continued from late May until early October with some winter visits and the inclusion of the third tributary stream. Samples from Headwater Pond were first taken in August and September of 1978. In 1979 a monitoring regime identical to that of Spruce Pond was started on Headwater Pond and its inlet and outlet. Occasional samples were obtained from Headwater Pond's southwest intermittent inlet in 1982. Samples from Little Gull Lake were first taken in the summer of 1978 and later, as time permitted.

BIOLOGICAL DATA

Biological data from the Experimental Ponds Area have been described in reports on metazoan fish parasites (Cone and Ryan 1984), zooplankton (Ryan 1982, 1984a), and Atlantic salmon and brook trout (Ryan et al. 1981; Ryan 1984b). All aquatic life forms collected have been assigned codes documented

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[2]Supervisor of Forestry, central region, Department of Forest Resources and Lands, Government of Newfoundland and Labrador.

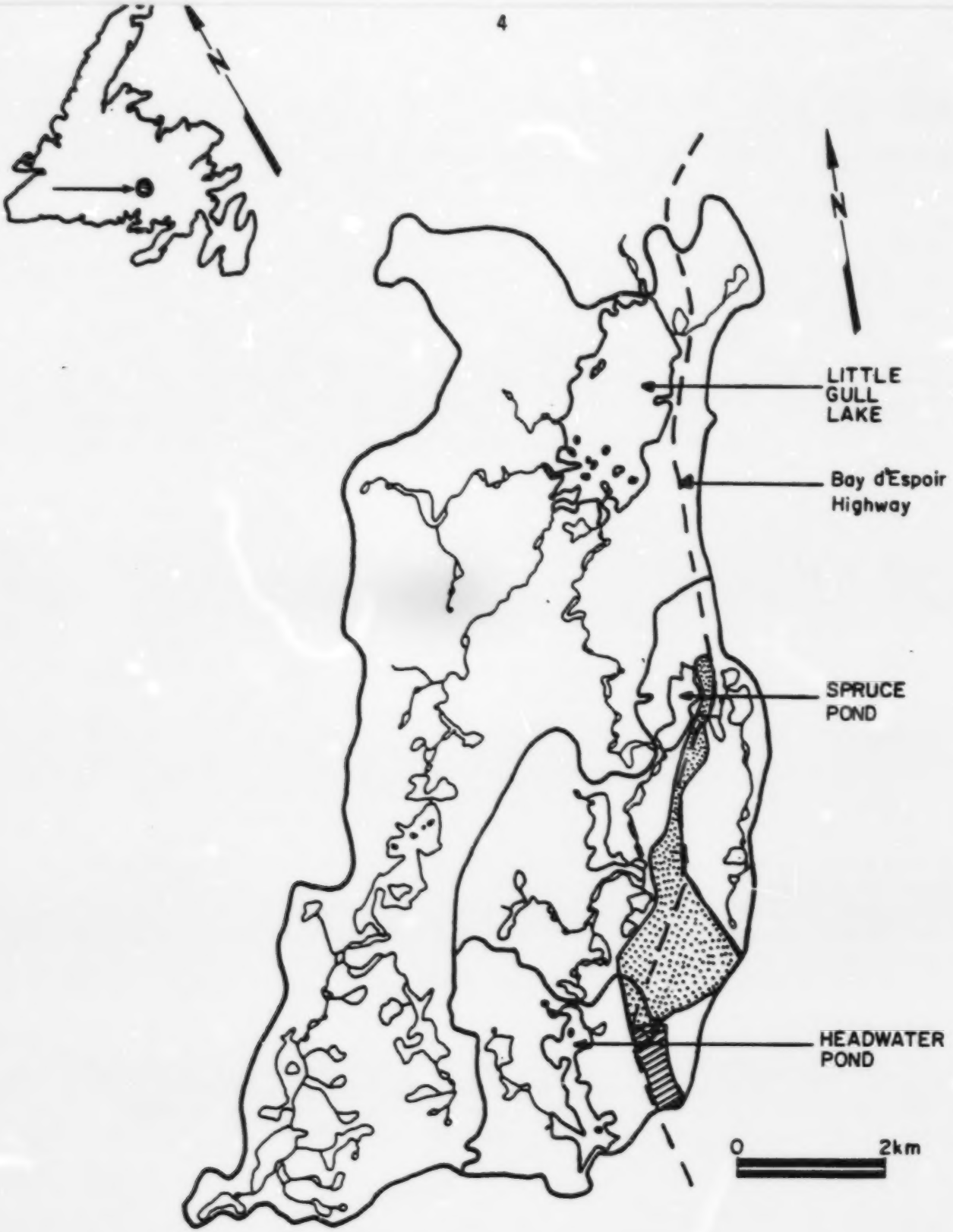

Fig. 2. Locations of logging operations from 1979 to 1981 (stippled) and clearcutting in 1982 (hatched) in the catchment basin of the Experimental Ponds Area.

by Ryan (1983a, 1983b) and data have been stored, with appropriate sample dates and locations, on computer files. Future reports will document additional biological aspects.

MATERIALS AND METHODS

PHYSICAL LIMNOLOGY

Depth measurements or soundings were made on the lakes with a graduated sounding pole (Spruce and Headwater ponds) or a Ferrograph 500 echosounder (Little Gull Lake). Hydrographic contour maps and morphometric data were obtained in the laboratory with the aid of the sounding data, topographic maps and aerial photographs as described in Welch (1948).

Annual flushing rates were approximated by the method used by Kerekes (1975);

$$\text{Flushing rate} = \frac{\text{Runoff} \times \text{Drainage Area}}{\text{Lake Volume}}$$

using the average runoff for insular Newfoundland of 28.65×10^{-3} m^3 sec^{-1} km^{-2} over the period 1949-62 (Murray and Harmon 1969).

Stream velocities and rates of flow were measured, starting in 1978, at approximate two week intervals, concurrent with other physical and chemical measurements, with a watch, rule, tape measure, and a floating object such as a twig at the stream sampling locations (Fig. 3). Depth and velocity were measured, typically three times, approximately equidistant across the measured stream width. Rate of flow was calculated as the product of the average depth measurement, the average velocity measurement, and the stream width. No attempt was made to measure flows in winter or when rivers were considered to be too high for safe wading. On July 4 - 5, 1979, stream sections from the origin of Headwater Pond's inlet to Spruce Pond's outlet at Little Gull Lake were surveyed on foot. In this report bottom types are classified according to Hynes (1970) and the amount of Atlantic salmon and brook trout spawning substrate is estimated using particle size criteria of Porter (1975) and Witzel and MacCrimmon (1983), respectively.

Starting in 1980, water levels of Spruce and Headwater ponds were measured, concurrent with other physical and chemical measurements, by means of a nail and a ruler affixed to a rock face above the usual high water mark (Fig. 3). These lake bench mark measurements were the distances between the nail heads and the lake surfaces.

Ice thickness was measured during winter visits through a drilled hole with a ruler.

Water temperatures were measured at approximately mid-day in the streams and at the lake stations (Fig. 3) with a pocket thermometer, concurrent with water chemistry sampling. A Peabody-Ryan 30- or 90-day temperature recorder was installed in each of Spruce and Headwater ponds at the beginning of the open water field seasons. Water temperatures referred to in this report are

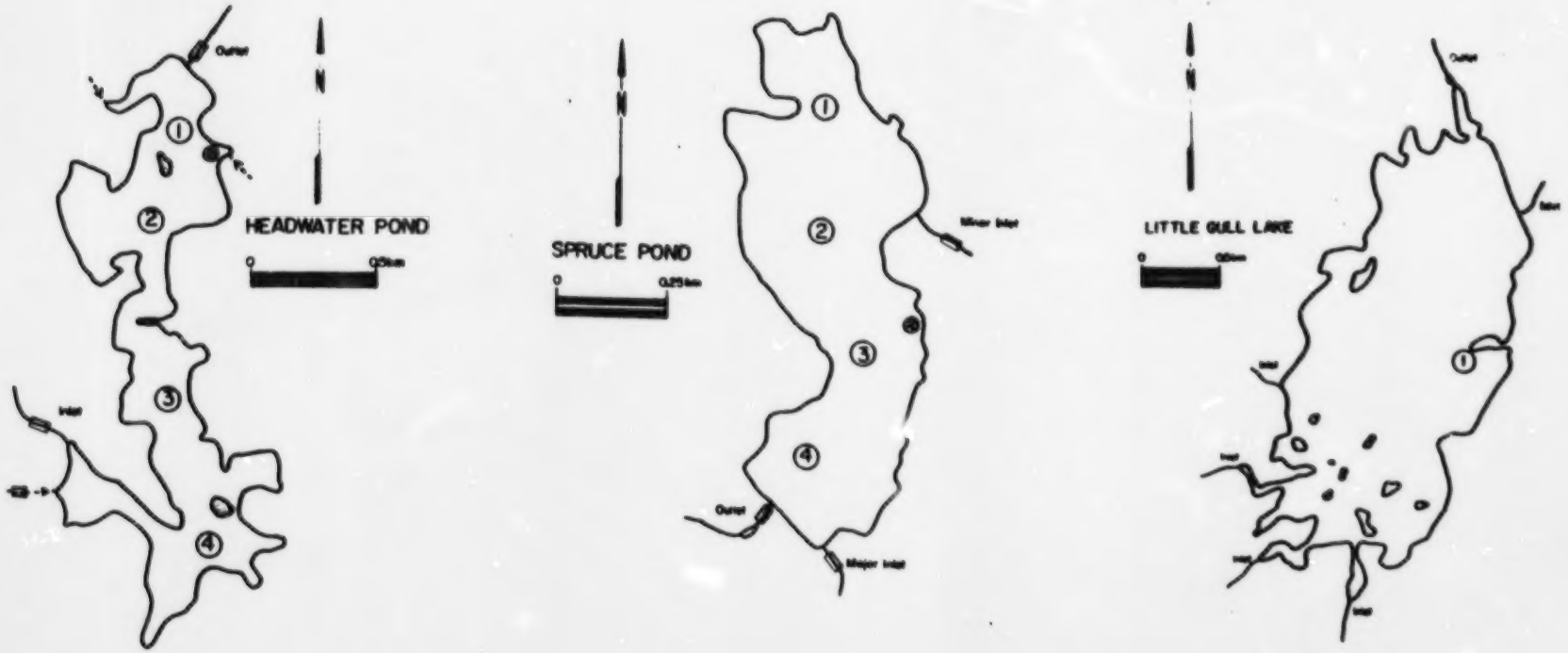

Fig. 3. Lake sampling stations (circled numerals), bench mark locations (circled X), and stream sampling locations (rectangles on streams) in the study area. Headwater Pond's intermittent rivulets are indicated by dashed lines.

the stream and lake temperatures taken at the time of water chemistry sampling and the weekly mean mid-day lake temperatures in the weeks that the water chemistry samples were obtained. Weekly mean mid-day lake temperatures for Spruce Pond in 1982 were those obtained from Headwater Pond in 1982 as the temperature recorder was stolen from Spruce Pond in that year.

Secchi disc readings were obtained around mid-day at the lake stations with a 20 cm diameter Secchi disc.

Turbidity and conductance were measured in lake and stream samples used for chemical analyses. Turbidity was measured with a Hach laboratory Model 2100 turbidity meter. Conductance was measured with a Yellow Springs Instruments conductivity bridge or a temperature-compensating Radiometer Model CDM2 conductivity meter. Results were reported as conductance at 25°C.

Precipitation records at Grand Falls and Bay D'Espoir were obtained from monthly records of Environment Canada (1977-82 inclusive).

CHEMICAL LIMNOLOGY

Analyses of water chemistry were made on subsurface samples obtained by immersing polyethylene or glass bottles to a depth of 0.1-0.5 m around mid-day. Most analyses were performed on samples taken at each of lake stations 1 and 4 of Headwater and Spruce ponds (Fig. 3) and from their tributaries at approximate two-week intervals from May to October. Occasional samples of these waters were obtained from November to April. Analyses of the waters of Little Gull Lake were performed on occasional samples obtained from one station (Fig. 3) in 1978, 1979, and 1980.

Samples taken from Spruce Pond in 1977 and its major inlet in 1978 were analysed at the Environment Protection Services' Halifax laboratory for the aminocarbamate, Matacil^{R}, by gas chromatography in the manner described by Coady (1978). These samples were taken before and after the Provincial Government's contractors sprayed the insecticide in an area about 13 km south of the catchment basin of the study area. As an additional check of water contamination by the spray, four Kromecote^{R} cards, upon which dyed spray droplets are detectable, were placed at locations around Spruce Pond in 1977.

Oxygen concentrations in lakes and streams were determined using the azide modification of the Winkler method (American Public Health Association et al. 1976) with phenylarsine oxide as a titrant. A Hach Kit Model CA-24WR was used immediately after samples were drawn on most sample dates from 1977 to 1979. With the Hach Kit, plastic powder pillows containing dry manganous sulphate, alkaline iodide-azide, and sulfamic acid were used and titration of 5.8 ml of sample was done with 0.0109 N phenylarsine oxide. Occasional use was made of standard 300 ml Winkler bottles with 2 ml aliquots of manganese sulphate, alkali-iodide-azide, and sulphuric acid. Titration of 200 ml of sample with 0.0250 N phenylarsine oxide was done the same day or the day after. From 1980 to 1982, 300 ml of sample were fixed in standard Winkler bottles with the dry Hach reagents. Titration of 200 or 300 ml of sample was done with 0.0250 N and 0.0375 N phenylarsine oxide, respectively, on the same day or the day after. Oxygen concentrations presented in the text are based on individual

measurements in most cases, except those from the lake stations from 1980 to 1982, which are the means of two samples.

The pH of lake and stream waters was measured in the St. John's, laboratory after a shelf life not exceeding 12 months at room temperature and, starting in 1979, in the field within 12 hours after samples were taken. A variety of electrometric equipment was used, dependent upon availability. Laboratory pH of the 1977 to 1979 samples was measured with a Corning Digital 109 meter or an Orion Model 401 meter. Starting in 1980, an Orion Model 407A meter was used for the laboratory pH measurements. Field pH was measured in 1979 with the Corning Model 10 meter. In 1980, field pH meters used were the Corning Model 10, the Orion Model 407A, or a Corning Model 3 Portable. In 1981 and 1982, the Orion Model 407A was used for field pH. All pH meters were used with a glass electrode and a reference electrode, except for the less sensitive Corning Model 3 Portable, which was used with a combination electrode. Meters were calibrated with buffers of pH 4 and pH 7 prior to use, except for the Corning Models 3 and 10, which were calibrated with pH 7 buffer only. Samples were stirred for five minutes prior to measuring pH.

The following analyses were done in the St. John's laboratory on lake and stream samples having a shelf life not exceeding 12 months at room temperature. Total hardness, defined as the concentration of calcium and magnesium ions expressed as calcium carbonate was determined using the Hach Chemical Co. modification of the EDTA method (American Public Health Association et al. 1976) with calmagite substituted as an indicator. Total alkalinity was determined by potentiometric titration for low alkalinity to pH 4.2 (American Public Health Association et al. 1976). For comparative purposes, alkalinities from a series of samples from Spruce Pond's minor inlet in 1982 were determined by total inflection point alkalinity (Gran titration) (Stumm and Morgan 1981), subsequent to the potentiometric titrations for low alkalinity. Calcium was determined with a Jarrel-Ash Model 82-270 Atomsorb or a Perkin-Elmer Model 403 atomic absorption spectrophotometer. Chloride was measured by the Hach Chemical Co. modification of the mercuric nitrate method (American Public Health Association et al. 1976) with diphenylcarbazone powder substituted as an indicator-buffer.

Phosphorus, nitrogen, and plant pigment concentrations in 1981 and 1982 samples from Headwater and Spruce ponds were measured by Memorial University's Water Analysis Facility.

Subsurface samples for phosphorus and nitrogen measurements were taken concurrent with other water samples, filtered through Whatman glass fibre filters, frozen the same day, and later transported to the university. Orthosphosphate and total phosphorus as PO_4 were measured from lake stations 1 and 4 in 1981 and from all lake stations in 1982 using the automated colorimetric-ascorbic acid method (Environment Canada NAQUADAT methods 15256 and 15406) (Inland Waters Directorate 1979). Nitrate and nitrite nitrogen as N from lake stations 1 and 4 in 1981 and from all lake stations in 1982 were measured by the automated cadmium reduction method (Environment Canada NAQUADAT method 07110) (Inland Waters Directorate 1979). Kjeldahl nitrogen as N was measured in the 1982 samples from station 1 on each lake. Samples were digested with sulphuric acid using a selenium catalyst and colorimetric

measurements were made with an autoanalyzer, similar to Environment Canada's NAQUADAT method 07015 (Inland Waters Directorate 1979). Ammonia nitrogen as N was measured in samples from all lake stations in 1982 using the indo-phenol blue method with an autoanalyzer (Environment Canada NAQUADAT method 07557) (Inland Waters Directorate 1979).

Subsurface water samples for the measurement of plant pigments were taken, concurrent with other samples, from lake stations 1 and 4 in 1981 and from all stations in 1982. Samples were filtered through Whatman glass fibre filters shortly after collection. Filters were frozen the same day and later transported to the university for measurements on individual samples in 1981 and on the pooled samples from the four stations on each lake on each sampling date in 1982. The spectrophotometric method (Environment Canada NAQUADAT method 06716) was used on samples taken up to the end of July 1982 and the fluorometric method (Environment Canada NAQUADAT method 06714) was used on samples taken after that time (Inland Waters Directorate 1979).

Phosphorus, nitrogen, and plant pigment concentrations were also measured by the Canadian Wildlife Service at Dalhousie University in water samples taken throughout the Experimental Ponds Area on July 14 and August 17, 1982. Subsurface lake and stream samples were cooled and shipped by road on July 14 and by air on August 17. Total unfiltered phosphorus as P, chlorophyll a, and phaeophytin were measured as described by Kerekes (1974). Nitrate and nitrite nitrogen as N and total organic nitrogen as N were measured in the unfiltered samples using Environment Canada NAQUADAT methods 07110 and 07601, respectively (Inland Waters Directorate 1979).

DATA STORAGE AND ANALYSIS

Study locations, morphometric features, lake flushing rates, results of pesticide analyses, precipitation data, a summary of ice thickness data, and the results of analyses done by the Canadian Wildlife Service are presented in this report. Data on the remaining 24 physical and chemical variables measured during the course of the study, including appropriate sample dates and locations, were stored on computer files. Codes for data retrieval are on file at the Northwest Atlantic Fisheries Centre.

Relationships among selected variables were examined by correlation analyses and least-squares regressions (SAS Institute 1979).

RESULTS AND DISCUSSION

LAKE MORPHOMETRY

The lakes are ranked, from largest to smallest, as Little Gull Lake, Headwater Pond, and Spruce Pond (Fig. 4-6, Tables 1 and 2). Little Gull Lake has about six times the water volume and four times the water area of Headwater Pond and about 15 times the volume and nine times the area of Spruce Pond. In contrast, Headwater Pond is a little more than twice as large as Spruce Pond.

Mean depth, a major determinant of lake trophic status (Ryder et al. 1974) is similar in both Headwater and Spruce ponds, 1.1 vs 1.0 m respectively.

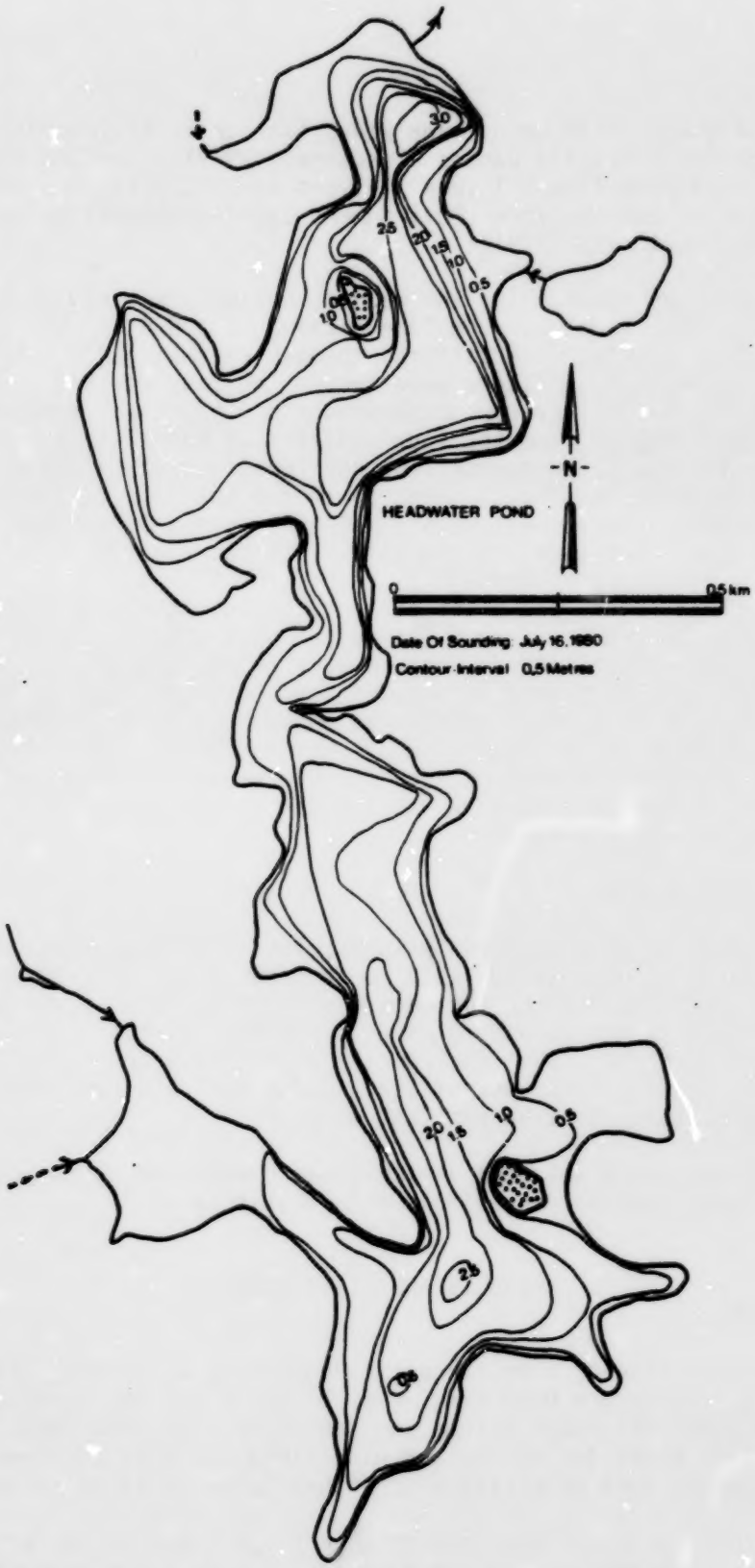

Fig. 4. Bathymetric map of Headwater Pond.

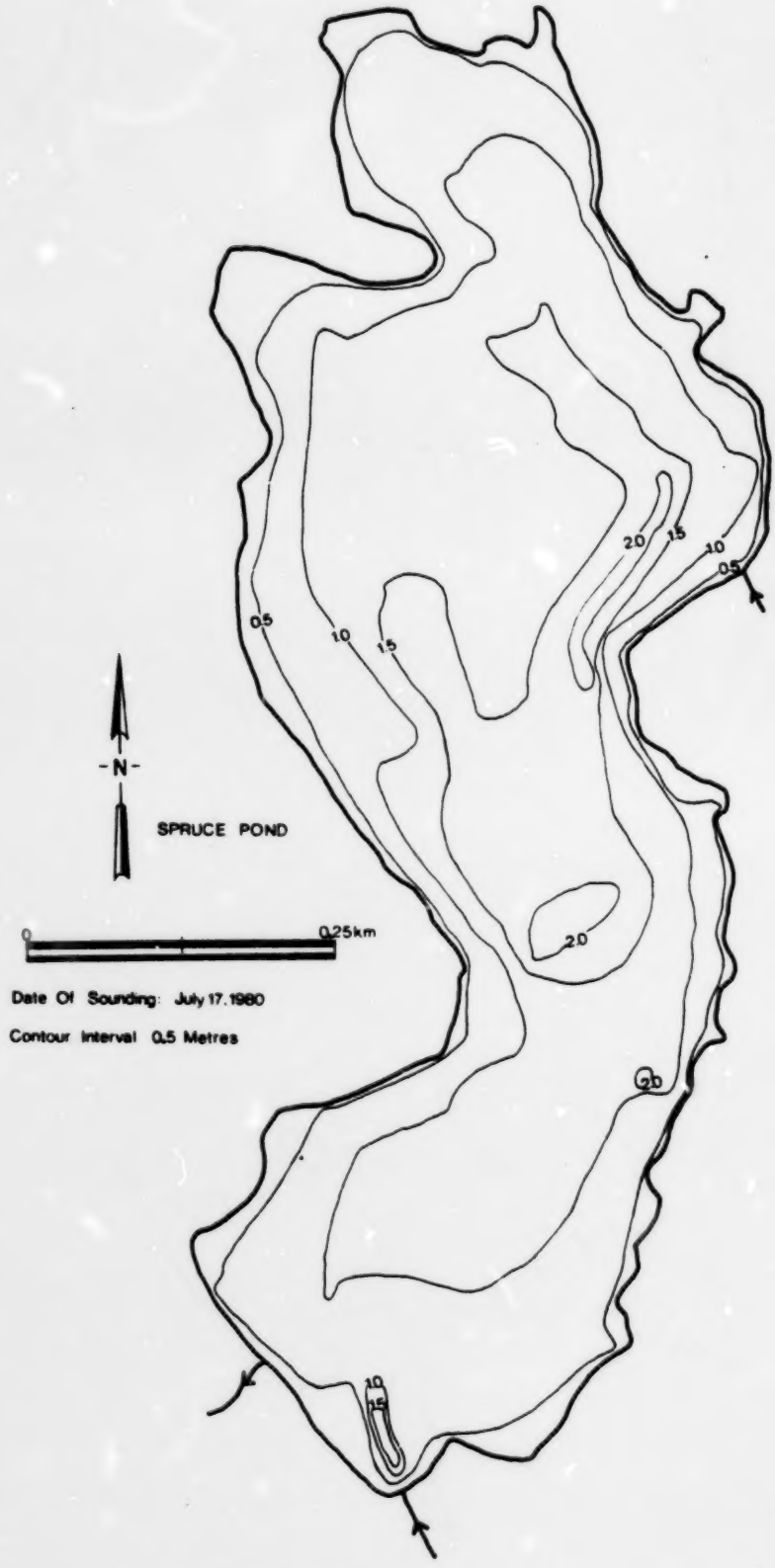

Fig. 5. Bathymetric map of Spruce Pond.

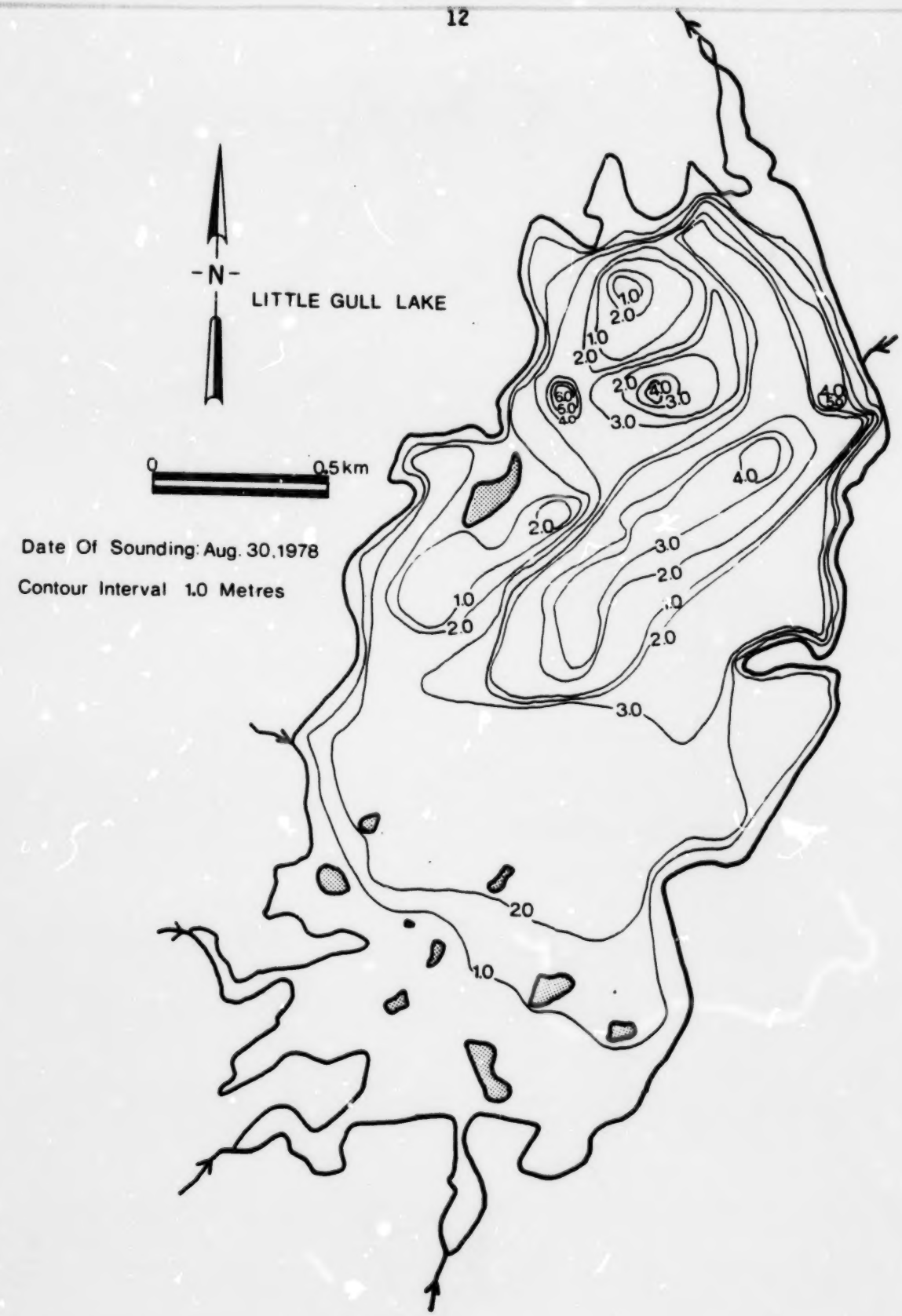

Fig. 6. Bathymetric map of Little Gull Lake.

Table 1. Location, morphometric features, and flushing rates of the study lakes.

Descriptor	Headwater Pond[a]	Spruce Pond[b]	Little Gull Lake[c]
Latitude	48°16'51"	48°19'40"	48°21'50"
Longitude	55°29'39"	55°28'24"	55°29'38"
Elevation (m)	226	215	186
Catchment basin area (km^2)	5.96	20.06	64.72
Lake area (ha)	76.81	36.50	312.10
Island area (ha)	0.69	0	5.62
Water surface area (ha)	76.12	36.50	306.48
Number of islands	2	0	10
Maximum length (km)	2.49	1.19	2.98
Maximum effective length (km)	1.23	1.19	2.98
Maximum width (km)	0.86	0.43	1.40
Maximum effective width (km)	0.86	0.43	1.40
Mean width (km)	0.31	0.30	1.03
Maximum depth (m)	3.25	2.13	6.30
Mean depth (m)	1.14	1.00	1.74
Shore length (km)	9.75	3.50	13.44
Island perimeter (km)	0.37	0	0.29
Shoreline development	3.10	1.64	2.15
Volume (m^3)	871,767	364,282	5,327,517
Volume development	1.05	1.41	0.83
Flushing rate (times yr^{-1})[d]	6.16	49.65	10.95

[a]Sounded July 16, 1980.

[b]Sounded July 17, 1980 and June 16, 1977. Soundings identical.

[c]Sounded August 30, 1978.

[d]$\frac{\text{Runoff x Drainage Area}}{\text{Lake Volume}}$ where runoff is mean runoff for Nfld. 1949-62 (Murray and Harmon 1969).

Table 2. Stratum interface areas (ha) and partial volumes (m^3) of the study lakes. Areas are the areas enclosed by the upper boundaries of the strata.

	Headwater Pond				Spruce Pond				Little Gull Lake			
Stratum	Area	(%)	Volume	(%)	Area	(%)	Volume	(%)	Area	(%)	Volume	(%)
0.0-0.5	76.12	(100.0)	326,267	(37.4)	36.50	(100.0)	167,950	(46.1)	306.48	(100.0)	1,363,733	(25.6)
0.5-1.0	54.96	(72.2)	237,283	(27.2)	30.76	(84.3)	124,533	(34.2)	240.35	(78.4)	1,176,200	(22.1)
1.0-1.5	40.33	(53.0)	164,417	(18.9)	19.48	(53.4)	58,233	(16.0)	230.17	(75.1)	1,024,317	(19.2)
1.5-2.0	25.96	(34.1)	88,217	(10.1)	5.30	(14.5)	12,633	(3.5)	180.56	(58.9)	777,850	(14.6)
2.0-2.5	10.48	(13.8)	39,783	(4.6)	0.56	(1.5)	933	(0.3)	131.85	(43.0)	509,100	(9.6)
2.5-3.0	5.68	(7.5)	14,433	(1.7)					74.50	(24.3)	235,400	(4.4)
3.0-3.5	0.82	(1.1)	1,367	(0.2)	Total		364,282	m^3	24.24	(7.9)	80,650	(1.5)
3.5-4.0					Max. depth		2.13	m	9.21	(3.0)	40,033	(0.8)
4.0-4.5	Total		871,767	m^3					6.86	(2.2)	31,400	(0.6)
4.5-5.0	Max. depth		3.25	m					5.72	(1.9)	27,700	(0.5)
5.0-5.5									5.36	(1.8)	26,500	(0.5)
5.5-6.0									5.24	(1.7)	26,017	(0.5)
6.0-6.5									5.17	(1.7)	8,617	(0.2)
									Total		5,327,517	m^3
									Max. depth		6.30	m

Little Gull Lake has a lesser potential productivity per unit surface area than the two upstream lakes on the basis of its greater mean depth of 1.7 m.

The study lakes are similar in size to the majority of Newfoundland headwater lakes described by Scruton (1983). Sixty percent of those 108 lakes were from 11 to 100 ha and 38% were from 101 to 1000 ha. Thirty-eight percent had maximum recorded depths of less than 3 m.

Headwater Pond, in contrast to Spruce Pond and Little Gull Lake, is comprised of two distinct basins nearly separated by a narrow peninsula (Fig. 4). Each basin is approximately the same size as Spruce Pond (Tables 3 and 4). Headwater Pond could, by virtue of these two basins, lend itself to whole lake experimentation in the future. For example, artificial separation of the basins could provide an opportunity to examine the effects of fish stock manipulation or physical/chemical habitat alteration.

Lake water volumes fluctuated considerably due to changing water levels from May to October and varying ice thickness in winter. Water level fluctuations, determined by bench-mark measurements from May to October, 1980 to 1982, were greater in Spruce Pond than in Headwater Pond, perhaps primarily due to the much lesser volume to drainage basin ratio in Spruce Pond. The range in recorded water level was 17.7 cm in Headwater Pond and 45.5 cm in Spruce Pond. Decreases in water levels of these amounts correspond to decreases in calculated lake volumes of about 15% of Headwater Pond and about 35% of Spruce Pond (Fig. 7). Similarly, ice thickness measured at the lake stations in February from 1978 to 1982 ranged from 36 to 61 cm (although some open, flowing stream water was always observed). This maximum corresponds to 42% of the calculated lake volume of Headwater Pond, 55% of Spruce Pond, and 26% of Little Gull Lake (Fig. 7). It represents a potentially frozen-to-bottom lake area of 22-32%. Thus, seasonal decreases in lake water volumes limit, to a large extent, the distribution and relative abundance of life forms throughout the system.

LAKE FLUSHING RATES

Estimated flushing rates indicated an eight-fold variation among the study lakes (Table 1). These rates should be considered as only crude approximations since they were derived from average insular Newfoundland runoff rather than runoff from the Experimental Ponds Area and they don't take into account variation in such factors as groundwater and surface flow within the study area, evaporation, and the considerable variation in water movement within the lakes.

The average Newfoundland runoff for the period 1949 to 1962 was slightly greater, by 1.1 times, than the average Gander River discharge downstream of Gander Lake (Murray and Harmon 1969). However, the average value may have better approximated the Experimental Ponds Area runoff than did the Gander River value. The study area was near the height of land near the middle of the island and was close to monitored runoff stations on the Terra Nova River and on the south coast which had greater than average Newfoundland runoff (Murray and Harmon 1969). The major factor prohibiting the use of these calculated

Table 3. Morphometric features of the two basins of Headwater Pond. Sounded July 16, 1980.

Descriptor	North basin	South basin
Lake area (ha)	35.57	41.24
Island area (ha)	0.24	0.45
Water surface area (ha)	35.33	40.79
Number of islands	1	1
Maximum length (km)	1.10	1.39
Maximum effective length (km)	1.04	1.11
Maximum width (km)	0.68	0.86
Maximum effective width (km)	0.68	0.86
Mean width (km)	0.32	0.29
Maximum depth (m)	3.25	2.75
Mean depth (m)	1.36	0.96
Shore length (km)	4.11	5.64
Island perimeter (km)	0.14	0.23
Shoreline development	1.95	2.49
Volume (m^3)	479,536	392,231
Volume development	1.25	1.05

Table 4. Stratum interface areas (ha) and partial volumes (m^3) of the two basins of Headwater Pond. Areas are the areas enclosed by the upper boundaries of the strata.

	North basin				South basin			
Stratum	Area	(%)	Volume	(%)	Area	(%)	Volume	(%)
0.0-0.5	35.33	(100.0)	157,240	(32.8)	40.79	(100.0)	169,027	(43.1)
0.5-1.0	27.72	(78.5)	123,139	(25.7)	27.24	(66.8)	114,144	(29.1)
1.0-1.5	21.66	(61.3)	91,648	(19.1)	18.67	(45.8)	72,769	(18.6)
1.5-2.0	15.19	(43.0)	58,059	(12.1)	10.77	(26.4)	30,158	(7.7)
2.0-2.5	8.37	(23.7)	34,183	(7.1)	2.11	(5.2)	5,600	(1.4)
2.5-3.0	5.41	(15.3)	13,900	(2.9)	0.27	(0.7)	533	(0.1)
3.0-3.5	0.82	(2.3)	1,367	(0.3)				
	Total		479,536 m^3		Total		392,231 m^3	
	Max. depth		3.25 m		Max. depth		2.75 m	

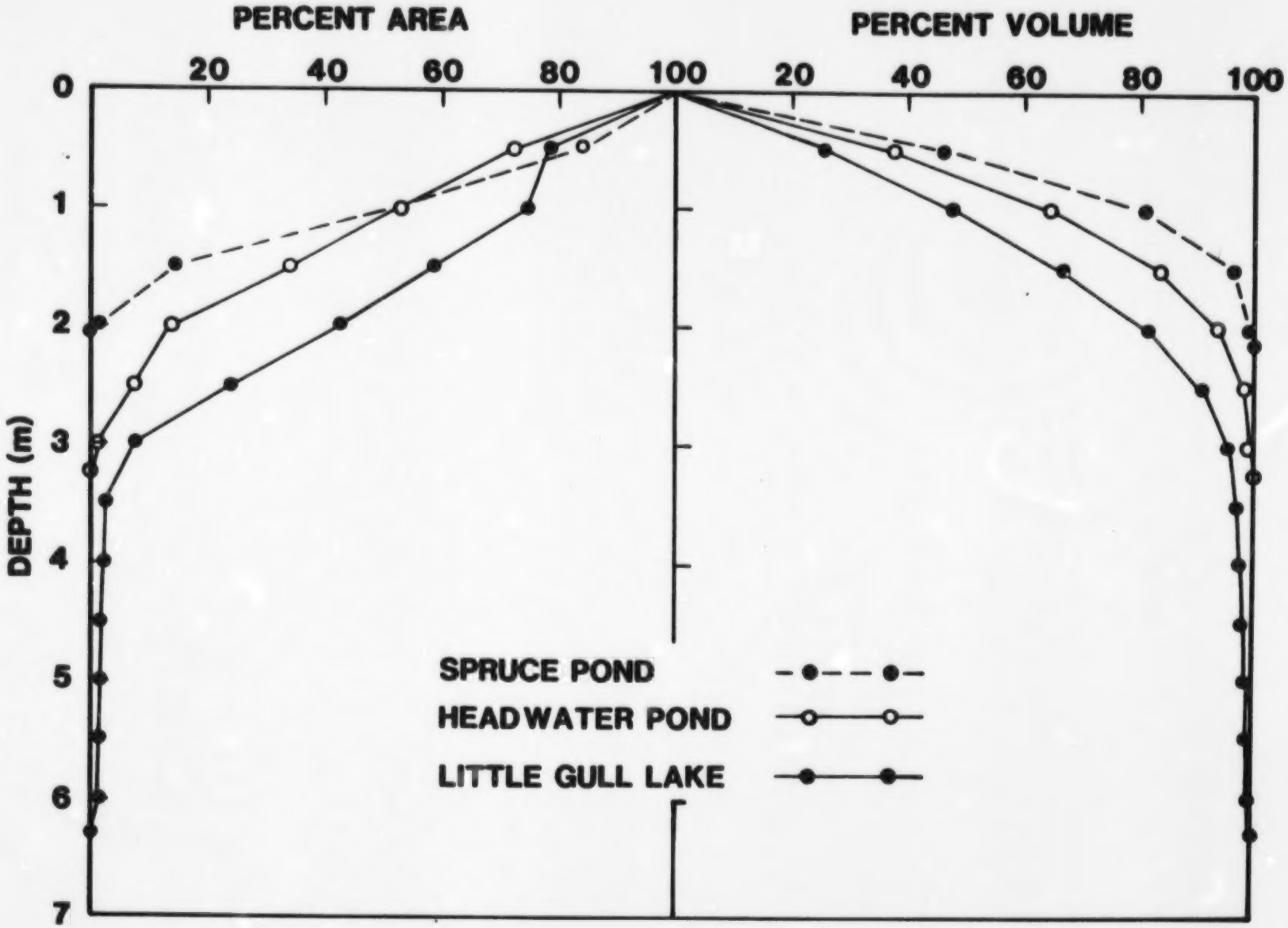

Fig. 7. Depth-area and depth-volume curves of the study lakes.

rates for precise comparison is the variation in water movement within the lakes.

Most of the flow from the inlets to Headwater Pond and Little Gull Lake must travel large distances through the lakes to reach the outlets. In contrast, water entering Spruce Pond via its major inlet can readily exit through the outlet without circulating through the entire lake. Average measured stream flow in Spruce Pond's minor inlet during the May to October period from 1978 to 1982 was only 0.09 m^3 sec^{-1}. Average measured flows in the major inlet and outlet from 1978 to 1982 were 0.87 m^3 sec^{-1} and 0.59 m^3 sec^{-1} respectively. Thus, although Spruce Pond's water movement is contributed to by the minor inlet, water replacement is probably faster in the southern portion of the lake than it is in the northern portion.

The average measured outlet flows divided by the respective lake volumes indicate a water replacement rate during the May to October period of 20.1 times yr^{-1} for Headwater Pond and 50.9 times yr^{-1} for Spruce Pond, consistent with the large between-lake differences in estimated annual flushing rates. Large differences in flushing rates can be expected due to the large variation in catchment basin area to lake volume ratios.

Large differences in flushing rates between lakes can be expected to account for between-lake differences in faunal abundance since rapid flushing can limit faunal densities via mechanisms such as the physical removal of organisms or their food (O'Connell and Andrews 1977; Ryan 1984a).

SUBSTRATES

Physical components of each of the lake bottoms range from mud and humic silt to detritus, rubble, boulders, and bedrock. A rocky substrate is characteristic of all streams at the locations used for water sampling and flow measurements, with the exception of Spruce Pond's minor inlet. Headwater Pond's inlet is about 80% cobble, pebble, and gravel, 20% boulders, and 2.8 m wide at the sampling site. Headwater Pond's outlet is about 50% boulders, 30% bedrock, and 10% gravel and pebble, and 8.6 m in width. The occasional sampling of Headwater Pond's southwest intermittent inlet was done on bedrock with an average streambed width of 0.8 m. Spruce Pond's major inlet is 14.6 m wide at the sampling location adjacent to Spruce Pond and has a bottom consisting of about 90% boulders and 10% rubble and gravel. Spruce Pond's outlet sampling site is 9.2 m wide with a 70% bedrock substrate with 30% boulder, rubble, and gravel. Spruce Pond's minor inlet flows through a culvert, used for flow measurements, under the Bay D'Espoir highway. The stream immediately downstream of the culvert, used for water sampling, is about 3.4 m wide and comprised of fine gravel and very coarse sand. Throughout the system, humic silt is characteristic of slow-water areas.

Considering stream sections in their entirety, boulders are the dominant substrate of all sections examined except Spruce Pond's minor inlet which is dominated by silt (Table 5). Only a small part of the system upstream of Little Gull Lake is comprised of ideal salmonid spawning substrate and most of this is between Spruce Pond and Little Gull Lake. In contrast, over 49,000 m^2

Table 5. Bottom composition and area of salmonid spawning substrate of stream sections from upstream of Headwater Pond to Spruce Pond's outlet at Little Gull Lake. The survey was conducted July 4-5, 1979. Standing waters are not included.

Stream section	Length (m)	Average width (m)	Bottom type[a]	% of total	Atlantic salmon spawning substrate[b] (m^2)	Brook trout spawning substrate[c] (m^2)
Headwater Pond's inlet	1270	2	Boulder	50	Nil	5
			Cobble	2		
			Pebble	48		
			Gravel	< 1		
Headwater Pond to pond between Headwater and Spruce ponds	699	9	Boulder	99	6	6
			Pebble	< 1		
			Gravel	< 1		
Pond between Headwater and Spruce ponds to Spruce Pond	445	10	Boulder	99	Nil	Nil
			Cobble	< 1		
Spruce Pond's minor inlet	2033	3	Silt	99	4	6
			Gravel	< 1		
Spruce Pond to Little Gull Lake	2160	11	Boulder	95	1020	216
			Pebble	4		
			Gravel	< 1		
Total	6607				1030	233

[a]Terminology after Hynes (1970).

[b]Atlantic salmon spawning substrate is defined here as particle size of 20-80 mm (Porter 1975).

[c]Brook trout spawning substrate is defined here as substrate having a particle size of 0.5-32.0 mm (Witzel and MacCrimmon 1983).

of suitable Atlantic salmon spawning habitat have been identified downstream of Little Gull Lake on the Little Gull River (Traverse 1972).

Salmonids, particularly brook trout, may spawn over a range of less than ideal conditions (Peterson 1978; Power 1980), but it is probable that the densities and migration patterns of salmonids in the study area are strongly influenced by the greater abundance of spawning habitat in downstream areas.

TEMPERATURE

Water temperatures were similar in Spruce and Headwater ponds and the highest lake temperatures of 23.0°C in Spruce Pond and 21.1°C in Headwater Pond were recorded in 1979 (Table 6). Higher temperatures were recorded in the streams, up to 28.0°C, and variation in the streams tended to be greater than in the ponds. Stream temperatures tended to be highest in Spruce Pond's minor inlet, as a result of its comparatively low flow and the proximity of the sampling area to a small, shallow pond.

Seasonal variation in water temperatures over the open-water period followed the usual pattern of a summer maximum occurring between spring and fall minima (Fig. 8). The average lake water temperature from May to October, 1977 to 1982, ranged from a low of 10.6°C in 1980 to a high of 15.1°C in 1979 with a grand mean of 13.4°C.

Water temperatures over 0°C can be expected to be highly correlated with air temperatures and may be useful in the prediction of biological phenomena such as salmonid production (Chadwick 1981). It may be that the mean temperatures are stronger correlates of temperature-related effects in the lakes than are the individual temperature measurements at the time of sampling. The weekly mean mid-day value may tend to compensate for short-term temperature variation such as that due to cloud cover or rainfall.

High temperatures can be expected to limit the distribution of life forms in the Experimental Ponds Area. The highest recorded water temperature, 28.0°C in Headwater Pond's outlet in August of 1979, was greater than the upper lethal temperature of 25.3°C for brook trout (Fry et al. 1946) and of 27.8°C for Atlantic salmon parr (Garside 1973). Both species can move to preferred areas of lower temperatures (Huntsman 1942; Gibson 1966). Similarly, high temperatures resulting in minimal water levels exert a considerable influence on the invertebrate benthic fauna (Hynes 1970).

STREAM FLOW AND VELOCITY

Measured rates of flow were greatest in Spruce Pond's major inlet (Table 6). Measurement error probably accounts for the lesser values obtained from Spruce Pond's outlet, the most downstream of the flow measurement stations and the one with the largest catchment basin. While it is possible that groundwater flow may account for some of the difference between the flow in Spruce Pond's major inlet and outlet, it is probable that flows in the major inlet were overestimated due to irregularities in the 90% boulder substrate. Greater irregularities in stream substrates require greater correction for flow reduction (Welch 1948). Other investigators have used stream gauges to

Table 6. Temperature, turbidity, stream flow, and stream velocity at sampling locations in the Experimental Ponds Area, 1977-82. Mean, ranges, and numbers of observations (bracketed) are shown.

Sampling Site	Sample temperature (°C)	Turbidity (J.T.U.)	Stream flow ($m^3 sec^{-1}$)	Stream velocity ($m\ sec^{-1}$)
Headwater Pond Inlet	13.1 0.0 - 27.5 (43)	1.5 0.4 - 4.0 (44)	0.19 0.02 - 0.55 (38)	0.33 0.09 - 0.64 (38)
Headwater Pond Intermittent Inlet (Southwest)	12.5 11.0 - 14.0 (2)	2.5 1.5 - 4.0 (5)	0.02 0.01 - 0.04 (5)	0.26 0.11 - 0.35 (5)
Headwater Pond Station 4	13.7 1.5 - 21.1 (41)	1.1 0.3 - 3.0 (41)	-	-
Headwater Pond Station 1	13.2 0.0 - 20.6 (45)	1.0 0.3 - 3.0 (46)	-	-
Headwater Pond Outlet	13.8 0.3 - 28.0 (43)	1.5 0.4 - 5.0 (44)	0.56 0.14 - 1.75 (37)	0.35 0.11 - 0.84 (37)
Spruce Pond Major Inlet	13.3 0.0 - 24.5 (66)	1.5 0.3 - 8.0 (67)	0.87 0.00 - 3.43 (45)	0.21 0.00 - 0.59 (45)
Spruce Pond Minor Inlet	14.1 0.1 - 24.0 (53)	1.8 0.4 - 15.0 (54)	0.09 0.00 - 0.35 (43)	0.44 0.00 - 1.02 (43)
Spruce Pond Station 1	13.3 0.0 - 23.0 (65)	1.1 0.2 - 3.0 (65)	-	-
Spruce Pond Station 4	13.7 2.0 - 21.0 (60)	1.5 0.3 - 7.0 (60)	-	-
Spruce Pond Outlet	12.9 0.0 - 23.0 (67)	1.2 0.3 - 6.0 (67)	0.59 0.00 - 1.76 (46)	0.20 0.00 - 0.71 (46)

. . . continued

Table 6. (cont'd)

Sampling Site	Sample temperature (°C)	Turbidity (J.T.U.)	Stream flow ($m^3 sec^{-1}$)	Stream velocity ($m\ sec^{-1}$)
Little Gull Lake	10.5 2.0 - 15.5 (3)	1.1 0.5 - 2.0 (7)	-	-
All sites	13.4 0.0 - 28.0 (529)	1.4 0.2 - 15.0 (500)	0.46 0.00 - 3.43 (214)	0.30 0.00 - 1.02 (214)

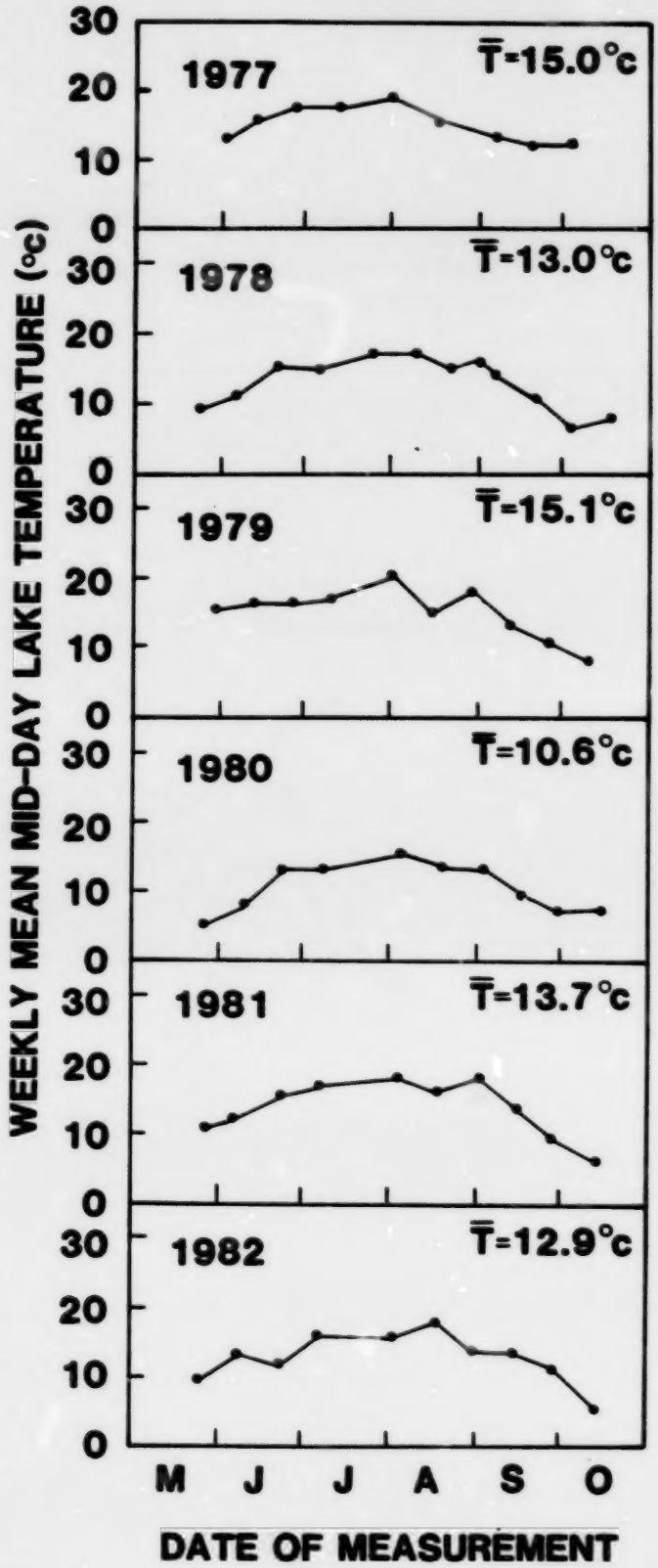

Fig. 8. Seasonal variation in weekly mean mid-day temperatures in Spruce Pond, 1977 to 1982. Values are from weeks in which water samples were taken during the open-water period. Values for 1982 were obtained from Headwater Pond. The average of plotted values for each year is indicated by $\bar{T}$.

compensate for such factors (Schindler et al. 1976); a procedure not considered logistically practical in the present study. More accurate flow measurements were possible on Spruce Pond's outlet over a comparatively smooth, 70% bedrock substrate.

Maximum velocities and rates of flow in the study area were probably not encountered as maximum flows on the Gander River typically occur in early May (Murray and Harmon 1969), prior to the start of the spring field season.

No measurable flow occurred at the sampling locations in Spruce Pond's major inlet, minor inlet, and outlet on several occasions during the warm summers of 1978 and 1979 and average flows in all streams were highest during the coolest sample year of 1980 (Fig. 9). However, the mean May to October flow in Spruce Pond's outlet, the most reliably measured flow of the two longest time series, was not significantly related ($r = -0.58$, $p > 0.05$) to the mean May to October mid-day lake temperature over the period 1978 to 1982.

The mean May to October flow of Spruce Pond's outlet was the lowest during 1978 when the mean May to October precipitation at Grand Falls was the least and its average flow was the highest in 1980 when the average monthly Grand Falls precipitation was the greatest (Fig. 9, Table 7). The mean May to October flow of Spruce Pond's outlet was more closely related to the mean May to October precipitation at Grand Falls over the period 1978 to 1982 ($r = 0.82$) than it was to the mean May to October precipitation at Bay D'Espoir ($r = 0.60$) for the same period (Fig. 9, Table 7). Although neither trend was statistically significant ($p > 0.05$), the greater correspondence of Spruce Pond's outlet flow to Grand Falls precipitation may have been a result of Grand Falls being a greater distance inland than Bay D'Espoir and thus less subject to isolated marine disturbances.

The mean May to October precipitation at Grand Falls was not significantly related ($p > 0.05$) to the mean May to October mid-day lake temperature over the period 1978 to 1982 ($r = -0.45$).

The expected association of greater stream flow with greater precipitation and lower temperature was apparent when the mean May to October Spruce Pond outlet flow (Y) was regressed on the mean May to October Grand Falls precipitation divided by the mean May to October mid-day lake temperature (X) for the period 1978 to 1982. The two variables were significantly related ($p < 0.05$) by the equation:

$$Y = 0.107 + 0.073X, \quad r = 0.89.$$

Seasonal variation in the flow of Spruce Pond's outlet, contrasted with monthly precipitation at Grand Falls (Fig. 10), was also indicative of the marked modifying effect of temperature on stream flow in the study area. Generally, flows tended to decline over the summer and rise in the fall. During some periods, such as June to October of 1978, May to July of 1980, and most of 1982, increases and decreases in monthly precipitation were associated with concurrent increases and decreases in stream flow, indicative of a near saturation of the watershed and rapid transfer of rainfall to stream runoff. At other times, particularly the comparatively warm period of May to July of

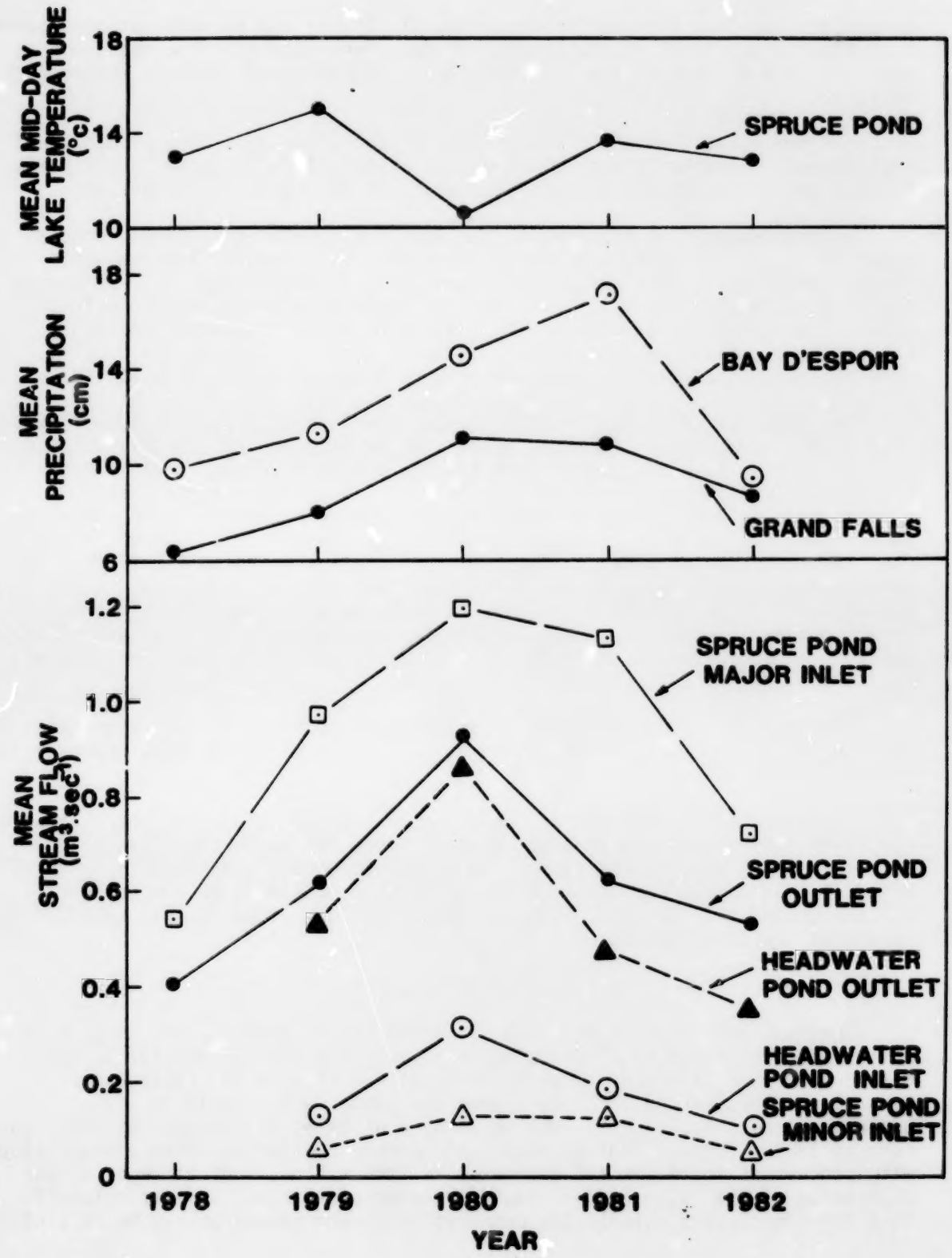

Fig. 9. Annual average mid-day Spruce Pond temperature, precipitation at Bay D'Espoir and Grand Falls, and stream flows, May to October, 1978 to 1982.

Table 7. Total monthly precipitation (mm) at Grand Falls (GF) and Bay D'Espoir (BE), May to October, 1977 to 1982 (Environment Canada 1977, 1978, 1979, 1980, 1981, 1982).

		May	June	July	August	September	October	Mean
1977	GF	98.2	65.2	101.2	48.1	86.9	140.1	90.0
	BE	96.0	101.2	117.9	92.3	199.4	209.0	136.0
1978	GF	35.1	73.9	64.5	56.3	54.9	90.8	62.6
	BE	81.6	149.7	80.0	38.9	107.7	131.5	98.2
1979	GF	47.9	24.4	79.3	155.3	76.2	99.3	80.4
	BE	76.8	60.3	104.3	111.2	138.8	188.2	113.3
1980	GF	112.8	144.1	99.9	152.0	83.2	80.4	112.1
	BE	102.8	211.5	139.6	145.9	146.9	135.9	147.1
1981	GF	111.6	118.6	58.5	84.0	114.4	159.8	107.8
	BE	216.6	122.0	156.8	123.3	211.0	201.2	171.8
1982	GF	89.3	76.5	101.0	52.8	94.0	108.7	87.1
	BE	68.3	137.5	109.0	74.2	107.0	70.9	94.5

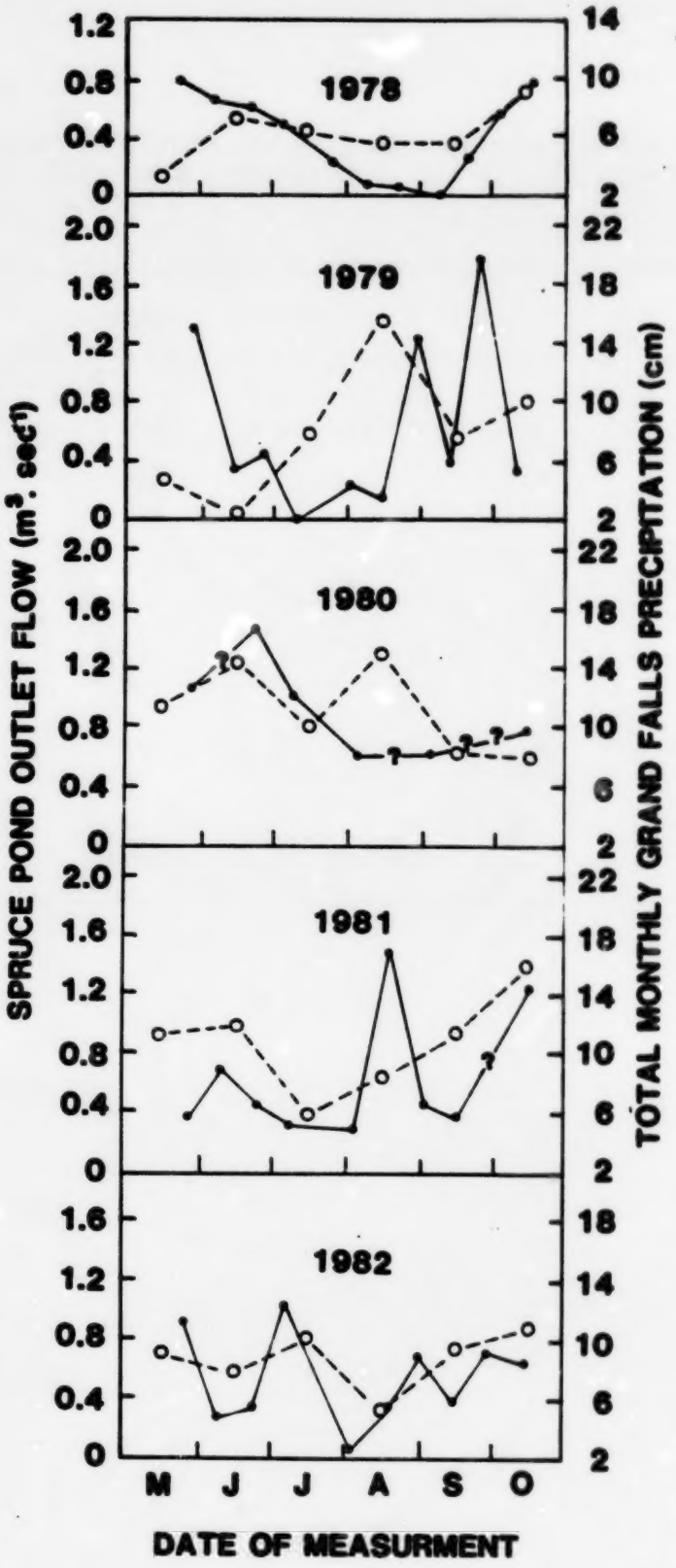

Fig. 10. Seasonal variation in Spruce Pond's outlet flow (solid lines) and precipitation at Grand Falls (dashed lines), May to October, 1978 to 1982. Question marks indicate absence of flow measurements as water levels were too high for safe wading.

1979, a lag occurred between periods of heavy rainfall and high stream flow, indicative of an absorption of precipitation by the dry watershed prior to stream runoff. In the comparatively wet summer of 1980, technical staff were unable to obtain stream flow measurements during and after periods of high rainfall (Fig. 10). Short-term flooding occurred between May and October in four of the five years from 1978 to 1982, but highest water levels occurred in 1980, concurrent with the highest precipitation at Grand Falls and the lowest water temperature.

Accurate modelling of a water budget in the Experimental Ponds Area and other such study areas would require the use of stream gauging techniques, water table measurements, and on-site measures of precipitation, transpiration, and evaporation.

Stream velocities and rates of flow are important factors controlling aquatic fauna. Measurements of these variables will assist in the interpretation of biological variation in the lakes such as changes in zooplankton abundance (Ryan 1984a). Similarly, fluctuating stream flows affect the abundance of life forms in the streams. During low water levels, fish movement in the streams would be minimal and the community structure of benthic stream invertebrates would be altered, at least temporarily (Hynes 1970). Low water levels can be expected during periods of high temperature and low precipitation. Increased salmonid movements in streams are often associated with high water levels (Ruggles 1980) as is a reduction in invertebrate fauna (Hynes 1970). Generally, high water levels can be expected during periods of low temperature and high precipitation.

COLOR AND CLARITY

The waters of the study area have a similar overall appearance, being colored brown by humus from bogs in the drainage basin. Color measurements at six of the stream and lake sampling stations, taken in 1983 as part of the continuation of island-wide lake surveys (Scruton 1983), ranged from 35 to 60 Hazen Units (H.U.) with a mean of 49 H.U. (Scruton, personal communication). Headwater Pond's inlet and Spruce Pond's minor inlet had higher values of 100 H.U. and 180 H.U. respectively, characteristic of bog drainage. High color is characteristic of Newfoundland lakes and 52% of 108 Newfoundland lakes described by Scruton (1983) had color values of 16-50 H.U.

It is probable that light transparency in each of the polymictic study lakes is similar due to their similar concentrations of dissolved and particulate matter. A Secchi disk, used throughout the open-water period on Headwater and Spruce ponds, was always visible on the bottom at the sampling stations, up to 2.74 m in Headwater Pond and up to 2.13 m in Spruce Pond. One June and early and mid-September Secchi depths in Little Gull Lake were 4.88, 1.98, and 2.74 m, respectively, with a mean of 3.20 m. Thus, the entire lake bottom area of Spruce Pond and 95% or more of the bottoms of Headwater Pond and Little Gull Lake (Fig. 7, Table 2) can be considered as typically being in the euphotic zone, the region of active algal production (Moss 1980).

Of the 108 Newfoundland Lakes described by Scruton (1983), the mean Secchi depth was 2.7 m and the disc was visible on the bottom in 31% of the lakes.

Water clarity in the Experimental Ponds Area, as determined by turbidity measurements, ranged from 0.2 to 15.0 J.T.U. with a mean of 1.4 J.T.U. (Table 6). Turbidity tended to be lower in the lakes than in the more turbulent streams. Highest turbidity in the lakes occurred at Spruce Pond's station 4, the shallowest station and the one closest to the lake's major inlet; possibly as a result of wind-induced resuspension and effluent from the major inlet.

Turbidity values from the study area are usual for Newfoundland waters. Jamieson (1979) reported that Labrador lakes and streams ranged from 0.2 to 24 J.T.U. with 94% ranging from < 1.0 to 5.0 J.T.U. In 108 Newfoundland headwater lakes, with their lesser allochtonous input, the mean turbidity was 0.65 J.T.U. with a range of 0.22-3.10 J.T.U. (Scruton 1983).

PESTICIDE CONTAMINATION

There was no evidence to indicate that the waters of the Experimental Ponds Area were contaminated by insecticide spray in 1977 or 1978. Matacil^{R} concentrations of all water samples taken before and after spray operations in the two years were less than the detectable limits (Table 8). No results were obtained from the Kromecote^{R} cards used in 1977 as they were rained upon prior to collection and destroyed. No spraying was conducted near the Experimental Ponds Area in subsequent years.

OXYGEN

Dissolved oxygen concentrations measured (Table 9) were above the minimum concentration of 5.0 ppm considered acceptable for the maintenance of "good fish populations" (Leedy et al. 1981) and were, with the exception of two February stream measurements of 13 ppm, within the generally accepted range for fish development of 4 - 12 ppm (Lagler et al. 1962). However, the lowest oxygen concentrations, measured during the summer months, may have limited fish populations since sensitive salmonid larvae and eggs may experience oxygen distress at concentrations of 8.1 ppm or less (Davis 1975).

pH

The mean pH of the waters of the Experimental Ponds Area, determined in the laboratory, was 6.3; typical of Newfoundland's fresh waters. Jamieson (1974) reported a Newfoundland average laboratory measured pH of 6.4 and the median pH of 108 lakes measured in the field was 6.0-6.5 (Scruton 1983). More than a hundredfold variation in hydrogen-ion concentration was encountered in the Experimental Ponds Area, with pH ranging from 5.1 to 7.3 (Table 9).

Differences existed between pH values obtained in the field and those obtained in the laboratory. These differences are, for the most part, attributable to differing sensitivities of field and laboratory equipment. The average laboratory pH was higher than the average field pH, by 0.19 units, in 1979 but lower, by 0.22 units, in 1980. In those years, most field measurements were made with equipment less sensitive than that employed in the St. John's laboratory. In 1980 and 1981, the use of the same equipment for field and laboratory determinations resulted in a marked decrease in the

Table 8. Results of pesticide (Matacil[R]) analyses of water samples from the study area.

Date[a]	Time (hr)	Location	Matacil[R] concentration (ppm)[b]
16 06 77		Spruce Pond Station 1	< 0.001
16 06 77		Spruce Pond Station 4	< 0.001
20 06 77	1700	Spruce Pond Station 1	< 0.001
20 06 77	1700	Spruce Pond Station 4	< 0.001
30 06 77	0900	Spruce Pond Station 1	< 0.001
30 06 77	0900	Spruce Pond Station 4	< 0.0005
26 06 78	1640	Spruce Pond Major Inlet	< 0.0003
30 06 78	1455	Spruce Pond Major Inlet	< 0.0003
01 07 78	1200	Spruce Pond Major Inlet	< 0.0003
02 07 78	1200	Spruce Pond Major Inlet	< 0.0002
03 07 78	1200	Spruce Pond Major Inlet	< 0.0002
04 07 78	1000	Spruce Pond Major Inlet	< 0.0002
05 07 78	1045	Spruce Pond Major Inlet	< 0.0003
06 07 78	1100	Spruce Pond Major Inlet	< 0.0002
07 07 78	0920	Spruce Pond Major Inlet	< 0.0002
08 07 78	1010	Spruce Pond Major Inlet	< 0.0003
09 07 78	1210	Spruce Pond Major Inlet	< 0.0003
10 07 78	1330	Spruce Pond Major Inlet	< 0.0010
11 07 78	0900	Spruce Pond Major Inlet	< 0.0003
12 07 78	1200	Spruce Pond Major Inlet	< 0.0003
13 07 78	1030	Spruce Pond Major Inlet	< 0.0003
14 07 78	0930	Spruce Pond Major Inlet	< 0.0003
15 07 78	1115	Spruce Pond Major Inlet	< 0.0003
17 07 78	1400	Spruce Pond Major Inlet	< 0.0003
18 07 78	1410	Spruce Pond Major Inlet	< 0.0003
19 07 78	0930	Spruce Pond Major Inlet	< 0.0003

[a]Spray applications of Matacil[R] were made south of the catchment basin on June 19 and 29, 1977 and June 30 and July 4, 1978.

[b]Detection limit (0.0002 - 0.001 ppm) varied with variation in signal to noise ratio of detector. All concentrations are below detectable limit.

Table 9. Selected water quality measurements from the Experimental Ponds Area, 1977-82. Means, ranges, and numbers of observations (bracketed) are shown except where indicated.

Sampling site	Dissolved oxygen (ppm)[1]	pH (in laboratory)	Conductance ($\mu S\ cm^{-1}$ at 25°C)	Chloride (ppm)	Total hardness (ppm)	Calcium (ppm)	Alkalinity (ppm)
Headwater Pond Inlet	7.90-11.85	6.4	31.9	5.9	11	3.2	4.9
		5.7-7.3	17.1-198.0	2.5-58.5	5-24	1.7-4.8	1.5-9.0
	(41)	(44)	(44)	(44)	(44)	(44)	(44)
Headwater Pond Intermittent Inlet (Southwest)	-	6.6	36.8	6.0	11	4.0	5.9
		6.4-6.7	30.0-43.0	5.0-7.5	8-14	2.5-5.2	2.8-8.8
		(5)	(5)	(5)	(5)	(5)	(5)
Headwater Pond Station 4	7.60-12.20	6.5	35.6	5.1	12	3.7	4.7
		5.4-7.3	23.5-47.0	3.0-9.8	8-20	1.9-5.4	2.0-7.6
	(40)	(41)	(41)	(41)	(41)	(41)	(41)
Headwater Pond Station 1	7-11.80	6.4	33.8	5.1	12	3.3	4.1
		5.5-7.0	23.5-57.8	3.0-15.5	6-18	1.9-5.0	2.5-6.5
	(44)	(46)	(46)	(46)	(46)	(46)	(46)
Headwater Pond Outlet	8.00-12.10	6.4	33.3	5.0	11	3.3	4.0
		5.8-7.1	23.5-49.2	3.0-9.5	1-22	1.4-4.8	1.0-7.0
	(41)	(44)	(44)	(44)	(44)	(44)	(44)
Spruce Pond Major Inlet	7-13	6.3	33.1	5.2	11	2.8	4.7
		5.7-7.0	21.6-53.5	3.0-14.0	4-14	0.9-4.6	1.5-9.0
	(62)	(67)	(67)	(67)	(67)	(67)	(67)
Spruce Pond Minor Inlet	7-11.95	6.2	32.9	6.8	10	2.3	3.2
		5.1-6.8	13.0-291.6	2.5-77.0	4-40	0.7-3.9	1.0-11.0
	(49)	(54)	(54)	(54)	(54)	(54)	(54)
Spruce Pond Station 1	7.65-12	6.3	33.9	5.9	11	2.2	4.3
		5.7-6.8	23.5-63.7	3.5-12.5	6-16	0.8-3.7	2.0-8.0
	(61)	(65)	(65)	(65)	(65)	(65)	(65)
Spruce Pond Station 4	7-11.63	6.3	34.5	6.0	11	2.4	4.1
		5.6-7.0	21.6-72.4	3.5-14.5	6-15	1.1-4.0	2.0-10.0
	(57)	(60)	(60)	(60)	(60)	(60)	(60)

. . . Continued

Table 9. (cont'd)

Sampling site	Dissolved oxygen (ppm)[1]	pH (in laboratory)	Conductance ($\mu S\ cm^{-1}$ at 25°C)	Chloride (ppm)	Total hardness (ppm)	Calcium (ppm)	Alkalinity (ppm)
Spruce Pond Outlet	7.40-13	6.3	35.6	6.4	11	2.6	4.4
		5.7-6.8	23.8-119.8	3.5-37.0	6-15	1.3-4.1	2.0-8.0
	(61)	(67)	(67)	(67)	(67)	(67)	(67)
Little Gull Lake	8-10	6.2	62.4	14.7	12	1.9	2.7
		5.7-6.5	22.1-248.4	3.5-71.5	8-24	1.0-2.7	1.0-4.0
	(4)	(7)	(7)	(7)	(7)	(7)	(7)
All sites	7-13	6.3	34.3	5.9	11	2.8	4.3
		5.1-7.3	13.0-291.6	2.5-77.0	1-40	0.7-5.4	1.0-11.0
	(460)	(500)	(500)	(500)	(500)	(500)	(500)

[1]Ranges and numbers of observations only. Different significance levels due to different measurement techniques.

difference between the field and laboratory values with average laboratory pH being lower, by only 0.03 units, in 1981 and higher, by only 0.02 units, in 1982 than the average field pH. However, in some individual samples from each year, differences between the two types of measurements were in the opposite direction to the average difference observed in that year. These differences were likely contributed to by factors such as carbon dioxide release or gain during handling or storage and are indicative of the difficulties in measuring the pH of dilute waters (Golterman and Clymo 1969).

Other authors have reported that the field pH of dilute water samples differed from the laboratory pH by being higher, lower, or the same (Welch 1948, Kadlecek and Mohnen 1976, Scruton 1983). In the present study, laboratory pH was selected as the most repeatable measure of the hydrogen-ion concentration since laboratory pH was measured with equipment of comparable precision in all years and in those years when laboratory pH was measured with the same equipment as field pH, average values of both differed little. However, it is suggested that field pH measurements be continued since anthropogenic or marine inputs to natural waters may consist of substances contributing to larger differences between field pH and laboratory pH (Galloway et al. 1979, NRCC 1981).

Seasonal fluctuations in the pH of the waters of the Experimental Ponds Area, as exemplified by Spruce Pond's outlet (Fig. 11), exhibited no consistent pattern from year to year. pH declined from May to October in 1977, increased in 1978, was relatively stable in 1979, fluctuated markedly in 1980, and exhibited intermediate variation in 1981 and 1982.

The mean annual pH of Spruce Pond's outlet from May to October ranged from 6.1 to 6.6 and did not exhibit a consistent increase or decrease from 1977 to 1982 (Fig. 12). Increases and decreases in the mean annual pH of Spruce Pond's outlet were associated with increases and decreases in the mean annual weekly mid-day Spruce Pond temperature and, in three of five cases, with increases and decreases in the annual mean monthly precipitation at Grand Falls (Fig. 12); suggestive of temperature and precipitation regulation of pH. The mean annual pH was not significantly related ($p > 0.05$) to the mean annual temperature or precipitation but in individual samples throughout the study area ($N = 488$), pH was a significant ($p < 0.05$) positive correlate of sample temperature ($r = 0.12$).

Short-term changes in the pH of individual streams and lakes of 0.2 to 2.0 pH units have been reported from various regions (NRCC 1981). Such changes may result from factors such as acid precipitation, the input of marine aerosols, photosynthetic and respiratory reactions, and the flow of acidic bog waters (Wetzel 1975; NRCC 1981; Scruton 1983).

Scruton (1983) reported that he found no evidence to indicate that lake acidification due to acid precipitation was occurring in central Newfoundland and that the region in which the Experimental Ponds Area lies is of low to moderate sensitivity to acid precipitation.

Scruton (1983) reported a significant ($p < 0.01$) positive relationship between pH and conductance over the 108 Newfoundland lakes he examined and that

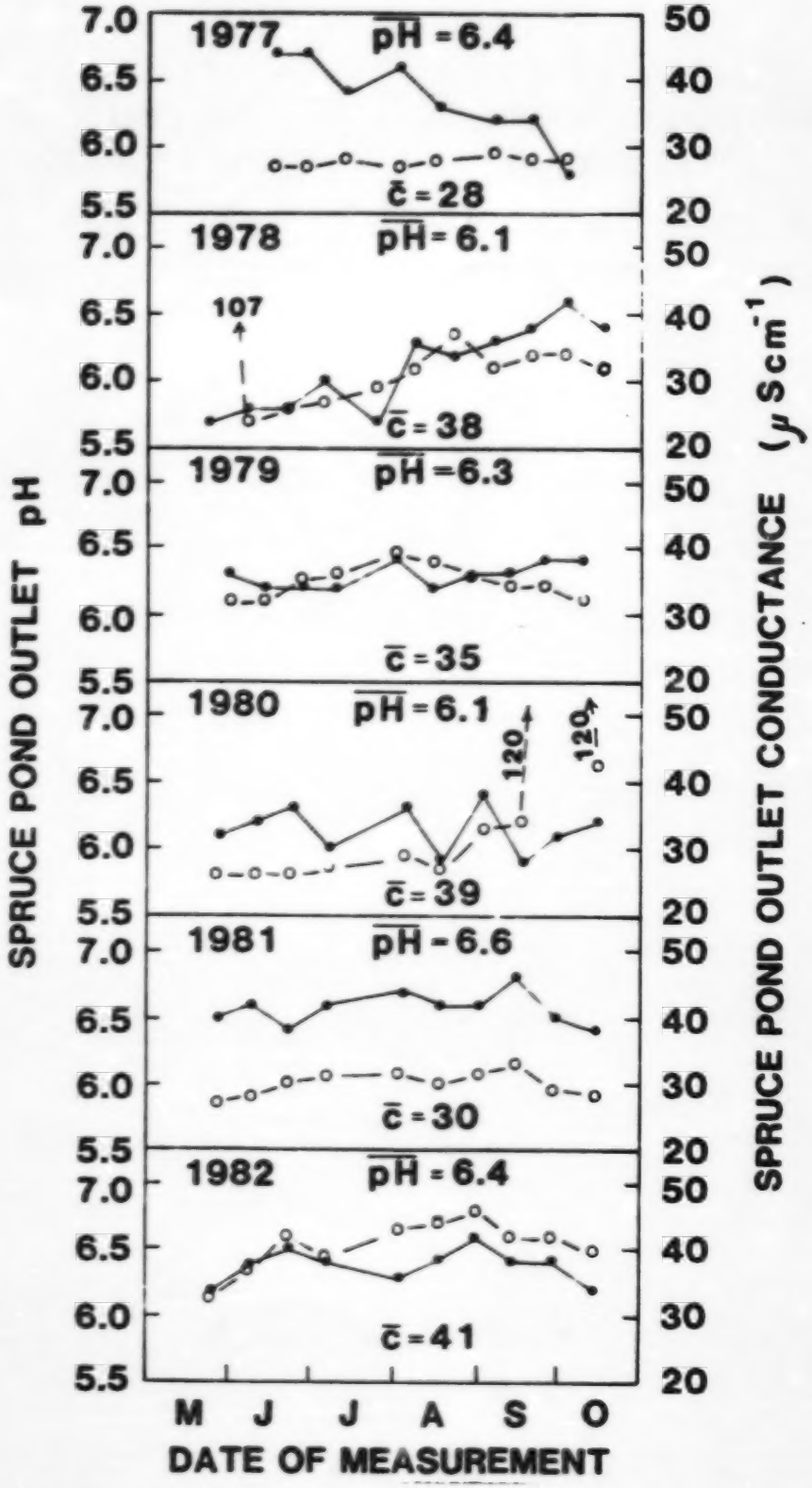

Fig. 11. Seasonal variation in pH (solid lines) and conductance (dashed lines) in Spruce Pond's outlet, May to October, 1977 to 1982. The averages of plotted values of pH and conductance for each year are indicated by $\overline{pH}$ and $\overline{C}$, respectively.

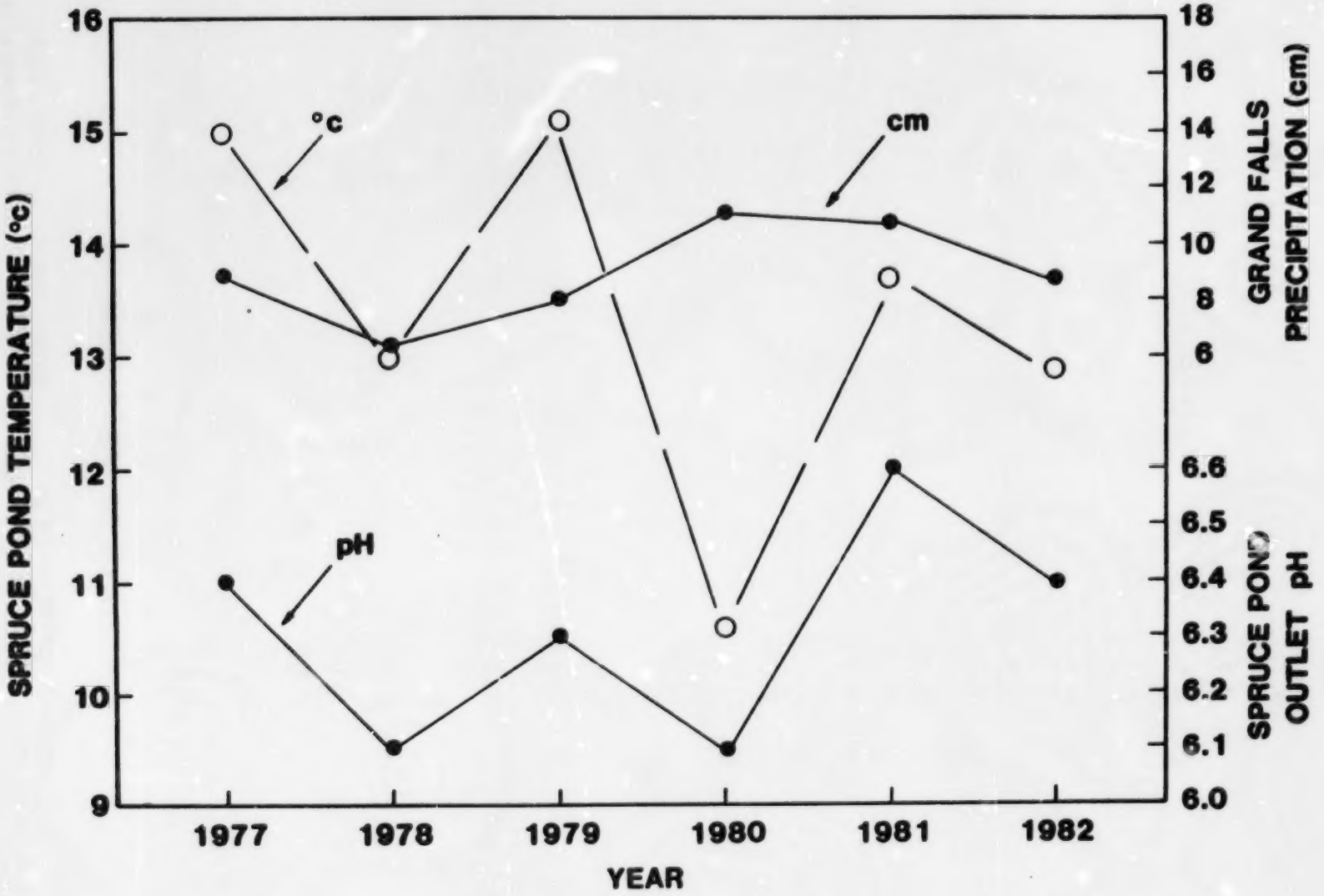

Fig. 12. Annual variation in mean weekly mid-day Spruce Pond temperature (from Fig. 8), mean monthly precipitation at Grand Falls (from Table 7), and mean Spruce Pond outlet pH (From Fig. 11) from May to October, 1977 to 1982.

marine aerosols strongly influenced conductance in Newfoundland lakes. Marine aerosols may, by their buffering action, affect lake pH (NRCC 1981). The pH of Spruce Pond's outlet from May to October was positively correlated with conductance (Fig. 11) in 1981 ($r = 0.76$, $p < 0.01$) and 1982 ($r = 0.69$, $p < 0.05$). However, pH was inversely related to conductance in 1977 ($r = -0.71$, $p < 0.05$) and not significantly correlated with conductance in the other three years. In individual samples throughout the study area ($N = 500$), pH was a significant ($p < 0.05$) but weak positive correlate of conductance ($r = 0.11$). Conductance in these samples was a significant ($p < 0.05$) positive correlate of chloride ($r = 0.95$); most of which is supplied by marine salts in Newfoundland's freshwaters (Kerekes and Hartwell 1980; Scruton 1983). Alkalinity in the individual samples was a significant positive correlate of conductance ($r = 0.44$) and a weaker, but significant, positive correlate of chloride ($r = 0.10$); suggestive of some buffering by marine aerosols.

It seems unlikely that carbon dioxide uptake during photosynthesis is a major factor affecting variation in measurements of pH from the study waters since pH did not typically exhibit an increase over the summer months and decrease in the fall following the usual pattern of primary production in Spruce Pond (Ryan unpublished data) and algal dependent zooplankton (Ryan 1984a). Similarly, the stirring of samples prior to pH measurement would tend to lessen pH differences due to differing solutions of dissolved gases.

It is probable that a number of factors regulate the hydrogen ion concentrations of the waters of the Experimental Ponds Area as in most other waters (Wetzel 1975; NRCC 1981). However, the dominance of bogs and podzol soils in the study area suggest that these are primary modifiers of pH in the study area. Runoff from bogs and podzol soils, influenced by temperature and precipitation, may serve as a source of hydrogen ion as well as providing buffering capacity (Wetzel 1975; Scruton 1983). The degree of such modification is complex and has been reported as being difficult to quantify (NRCC 1981; Scruton 1983). Differing amounts of precipitation, differing in source and chemistry, coupled with differing degrees of saturation of the drainage basin would result in varying degrees of influence of runoff.

Since the water chemistry of the Experimental Ponds Area is typical of Newfoundland's freshwaters as described by Jamieson (1974) and Scruton (1983), and since the dominance of bogs and podsol soils in the Experimental Ponds Area is characteristic of insular Newfoundland (Murray and Harmon 1969; Roberts 1983; Wells and Pollett 1983), it can be expected that the mechanisms modifying lake pH in the Experimental Ponds Area are similar to those occurring elsewhere on the island. Accurate modelling of a water budget, coupled with the additional analyses of groundwater and precipitation chemistry may clarify these mechanisms.

The hydrogen-ion concentration of the Experimental Ponds Area may be limiting fish production by its effect on food sources, or directly. The diversity of benthic invertebrates and zooplankton, important foods of fishes in the study area (Ryan 1984a, unpublished), are reduced in acid waters (NRCC 1981). The hatchability and growth of brook trout have been found to decrease at pH less than 6.5 (Menendez 1976), although other authors have reported lower critical values (NRCC 1981). Waters of pH below 5.5 have been considered as

borderline for the support of brook trout populations (Power 1980) and the critical pH for Atlantic salmon survival has been reported as 5.0 to 5.5 (Bua and Snekvik 1972; Jensen and Snekvik 1972). The presence of brook trout and landlocked Atlantic salmon in Newfoundland lakes was associated with higher pH (Scruton 1983). Possible survival mechanisms for salmonids in Newfoundland's acidic waters are the acquisition of a genetic tolerance (Swarts et al. 1978; Haines 1981) and the avoidance of highly acidic waters (Hoglund 1961; Johnson and Webster 1977).

CONDUCTANCE AND CHLORIDE

Conductance in the Experimental Ponds Area ranged from 13.0 to 291.6 μ S cm^{-1} with a mean of 34.3 μ S cm^{-1} (Table 9). Jamieson (1974) reported a range of 11.0 to 275.0 μ S cm^{-1} with a mean of 38.0 μ S cm^{-1} from 354 lake and stream samples while Scruton (1983) reported values of 11.4-119.0 μ S cm^{-1} with a mean of 28.9 μ S cm^{-1}. The higher values recorded in the present study and by Jamieson (1974), in comparison to Scruton's (1983) survey data, probably resulted from Scruton's headwater lakes being higher in their respective watersheds; resulting in proportionately less allochtonous input and lesser conductance (Wetzel 1975).

Conductance is a possible indicator of pollution loading, lake trophic status, nutrient concentrations, and the concentrations of other dissolved substances (Ryder 1982). In the Experimental Ponds Area, the concentrations of dissolved substances have been correlated with zooplankton abundance (Ryan 1984a). Similarly, conductance may assist in the prediction of the abundance of other life forms (Ryder 1982).

Seasonal variations in conductance, as exemplified by Spruce Pond's outlet (Fig. 11), was not consistent from year to year although an obvious pattern of an increase from spring values over the summer and a decrease in the fall occurred in 1979, 1981, and 1982. Marked increases in the conductance of Spruce Pond's outlet occurred in the spring of 1978 and the fall of 1980 and episodic increases in conductance occurred in most locations sampled. Some of these increases, particularly in Spruce Pond's minor inlet flowing under the Bay D'Espoir highway, were probably contributed to by road salt. Most were likely due to the input of marine salts. For example, the marked increase to 120 μ S cm^{-1} in Spruce Pond's outlet on September 30, 1980 (Fig. 11) was preceded two weeks earlier by an increase to 190 μ S cm^{-1} in Headwater Pond's inlet which is not subject to the influence of road salt. Both locations exhibited atypically high levels of chloride and conductance from September 16 to October 15, 1980. Chloride ion, a strong effector of conductance (Wetzel 1975), and conductance display occasional particularly high maximum concentrations in Newfoundland's precipitation arising from oceanic spray (Banfield 1983). Marine salts supply most of the chloride ion to Newfoundland's freshwaters (Kerekes and Hartwell 1980; Scruton 1983) and conductance measurements in the study area were highly correlated with chloride concentrations ($r = 0.94$, $N = 500$, $p < 0.01$).

The average chloride concentration in the Experimental Ponds Area of 5.9 ppm (Table 9) was slightly less than the 7.7 ppm average reported for 352 Newfoundland lake and stream samples by Jamieson (1974), likely as a

consequence of the distance of the study area from the ocean. Scruton (1983) reported a significant ($p < 0.01$) inverse relationship between chloride concentration and lake distance from the coast.

HARDNESS, CALCIUM, AND MAGNESIUM

The average total hardness measured in the Experimental Ponds Area (Table 9) was equal to the 11 ppm average reported by Jamieson (1974) for 354 Newfoundland lake and stream samples. All values were within the 1 to 150 ppm range encountered by Jamieson. The components of total hardness in the study area, calcium and magnesium, were also typical of Newfoundland's freshwaters. Calcium concentrations of 0.7 to 5.4 ppm in the Experimental Ponds Area averaged 2.8 ppm (Table 9), slightly greater than the 1.9 ppm average, but within the range of 0.5 to 17.5 ppm, reported by Jamieson (1974). Only 19% of Jamieson's 351 calcium samples had values greater than 2.0 ppm. Similarly, the conversion of total hardness and calcium to meq l^{-1}, the subtraction of calcium from total hardness, and the calculation of the Ca/Mg ratio, results in a mean Ca/Mg ratio of 1.8 in the Experimental Ponds Area. This average is within the range of 1.2 to 2.7 (mean near 2.0) reported by Scruton (1983) for Newfoundland headwater lakes in regions of low buffering capacity.

With calcium concentrations of less than 10 ppm, the waters of the Experimental Ponds Area are considered calcium deficient (Wetzel 1975). Accordingly, concentrations of total hardness and calcium can be expected to be correlates of the abundance of lake biota such as described by Ryan (1984a).

ALKALINITY

The average total alkalinity of 4.3 ppm (Table 9), determined by potentiometric titration for low alkalinity, was slightly less than the 6.7 ppm average of 348 Newfoundland lake and stream samples (Jamieson 1974). Jamieson (1974) reported a range of 1.0 to 95.0 ppm with 74% of his samples having values less than 5.0 ppm. Of 109 Newfoundland lakes described by Scruton (1983), the average alkalinity was 5.4 ppm (Scruton, personal communication).

Alkalinities measured in the laboratory may have slightly overestimated field alkalinities due to changes in carbon dioxide concentrations during handling and storage. Scruton (1983) found that field determinations of alkalinity with the more sensitive Gran technique (Stumm and Morgan 1981) produced results "generally lower" than results obtained in the laboratory with the potentiometric titration for low alkalinity, particularly with values of less than 5.0 ppm. He found that values obtained by both methods were highly correlated ($r = 0.97$). Comparisons of laboratory results obtained by potentiometric titration for low alkalinity (American Public Health Association et al. 1976) with those from laboratory Gran titrations (Stumm and Morgan 1981) using samples from Spruce Pond's minor inlet are consistent with these findings. Alkalinity measured by potentiometric titration for low alkalinity (X), ranging from 1.6 to 3.9 ppm, were, on the average, 0.5 ppm lower than those subsequently determined by Gran titration (Y). The two were significantly related by the regression equation:

$$Y = 0.51 + 1.01X \quad (r = 0.95, N = 11)$$

Loss of carbon dioxide from the samples during handling between the two determinations may account for this rise in alkalinity and it can be expected that slightly lower values would have been encountered in the field with lesser handling and storage as reported by Scruton (1983). From these results, it appears that in the Experimental Ponds Area, the bias in the alkalinity data is consistent and small.

Total alkalinities encountered in the present study indicate that the waters of the Experimental Ponds Area are typically of moderate sensitivity to acidification but vary from extremely sensitive to low in sensitivity (Scruton 1983). Long-term variation in alkalinity in the Experimental Ponds Area may serve as an indicator of lake acidification due to acid precipitation in lakes of central Newfoundland.

PHOSPHORUS, NITROGEN, AND PLANT PIGMENTS

Phosphorus, nitrogen, and plant pigment concentrations from the Experimental Ponds Area are, for the most part, characteristic of oligotrophic, humic lakes of low available phosphorus.

Total filtrable phosphorus concentrations determined by Memorial University in the 1982 lake water samples ranged from 2.0 to 47.9 mg P m^{-3} with a mean of 6.9 mg P m^{-3} (Table 10). The highest value, an outlier from Spruce Pond's station 2 on September 14, 1982, was not associated with extreme values at other locations. The average of 6.9 mg filtrable P m^{-3} was consistent with the slightly higher average value of 8.0 mg P m^{-3} determined by the Canadian Wildlife Service in unfiltered July and August samples taken throughout the study area (Table 11). Both averages were less than the maximum annual mean of 10 m P m^{-3}g characteristic of oligotrophic waters (Vollenweider and Kerekes 1981; Kerekes 1983) and were near the middle of the range reported for small oligotrophic lakes of Terra Nova Park, Newfoundland (Kerekes 1977). In Terra Nova Park, a low primary production of 1.8 mg C hr^{-1} can be expected in lakes having average total phosphorus concentrations of 8 mg P m^{-3} (Kerekes 1977).

Chlorophyll a measurements were consistent, for the most part, with the magnitude of total phosphorus concentrations. Two extremely high chlorophyll a values of 5.1 and 8.9 ppm determined by Memorial University (Table 10) probably resulted from macrophyte particles being taken in water samples. The remaining chlorophyll a measurements by Memorial University, averaging 2.6 mg m^{-3} in 1981 and 1982 overestimate average conditions as a result of the comparatively high detection limit in 1981. However, the average was close to the average of 2.5 mg m^{-3} in oligotrophic lakes (Vollenweider and Kerekes 1981; Kerekes 1983). Maximum measurements, exclusive of the two previously mentioned extremes, were close to the midpoint of maximum values encountered in mesotrophic lakes (Vollenweider and Kerekes 1981; Kerekes 1983); possibly as a result of sediment disruption and the sampling of benthic flora in the shallow-water lakes. Chlorophyll a concentrations determined with lower detection limits by the Canadian Wildlife Service averaged 0.77 mg m^{-3} (Table 11); suggestive of ultra-oligotrophic conditions (Vollenweider and Kerekes 1981; Kerekes 1983). The mean phosphorus concentration of 8.0 mg P m^{-3} and the mean chlorophyll a

Table 10. Results of phosphorus, nitrogen, and plant pigment measurements on filtered waters from Headwater and Spruce ponds, 1981-1982, by Memorial University Water Analysis Facility. Means, ranges, standard deviations (bracketed), and numbers of observation (N) are shown with minimum detection limit for each variable. Individual measurements less than or equal to detection limits were included as the detection limit. The forms of nutrients and pigments measured are indicated.

	Orthophosphate (ppm PO_4)[1] 1981-82 (filtrable inorganic phosphorus)	Total phosphorus (ppm PO_4)[1,2] 1982 (filtrable total phosphorus)	Nitrate and nitrite nitrogen (ppm N) 1981-82 (filtrable inorganic nitrogen)	Kjeldahl nitrogen (ppm N) 1982 (filtrable organic and ammonia nitrogen)	Ammonia (ppm N) 1982 (filtrable inorganic nitrogen)	Chlorophylla (ppm) 1981-82 (living pigment)	Phaeophytin (ppm) 1982 (decaying pigment)
Headwater Pond	0.007 < 0.003-0.019 (0.004) N=58	0.019 0.007-0.051 (0.010) N=40	0.021 < 0.002-0.190 (0.043) N=58	0.327 0.189-0.439 (0.068) N=10	0.005 0.002-0.009 (0.002) N=40	0.0026[3] 0.0008-0.017 (0.0038) N=18	0.0022 0.0013-0.0031 (0.0007) N=6
Spruce Pond	0.008 < 0.002-0.079 (0.011) N=58	0.023 0.006-0.147 (0.023) N=40	0.021 < 0.002-0.195 (0.042) N=58	0.376 0.233-0.479 (0.087) N=10	0.007 0.002-0.016 (0.003) N=40	0.0026[4] 0.0005-0.015 (0.0040) N=18	0.0022 0.0014-0.0033 (0.0008) N=6
Detection limit (PPM)	0.005 in 1981; 0.002-0.005 in 1982	0.05 in 1981; 0.003 in 1982;	0.005 in 1981; 0.002 in 1982	0.005	0.001	0.001 in 1981 and May-July, 1982; 0.001 August-October, 1982.	0.001

[1]For conversion of PO_4 to P, multiply by 0.326.
[2]1981 values not included because of high detection limit in that year.
[3]Extreme value of 8.900 ppm on June 8, 1982 not included.
[4]Extreme value of 5.100 ppm on June 8, 1982 not included.

Table 11. Results of phosphorus, nitrogen, and plant pigment measurements from the waters of the Experimental Ponds Areas, 1982, by the Canadian Wildlife Service. The forms of nutrients and pigments measured are indicated.

Location	Sample date	Total phosphorus (ppm P)[1] (total phosphorus)	Nitrate and nitrite nitrogen (ppm N) (inorganic nitrogen)	Total organic nitrogen (ppm N) (total organic nitrogen)	Chlorophylla (ppm) (living pigment)	Phaeophytin (ppm) (decaying pigment)
Headwater Pond Inlet	14/07/82	0.00872	0.02	0.35		
Headwater Pond Station 4	14/07/82	0.00688	0.01	0.29		
	17/08/82	0.00986			0.00071	0.00119
Headwater Pond Station 1	14/07/82	0.00642	0.04	0.25		
	17/08/82	0.00882			0.00108	0.00122
Headwater Pond Outlet	14/07/82	0.01018	< 0.01	0.21		
Spruce Pond Major Inlet	14/07/82	0.00826	0.01	0.27		
Spruce Pond Minor Inlet	14/07/82	0.00945	< 0.01	0.34		
Spruce Pond Station 1	14/07/82	0.00679	< 0.01	0.24		
	17/08/82	0.00652			0.00056	0.00107
Spruce Pond Station 4	14/07/82	0.00743	0.01	0.29		
	17/08/82	0.01193			0.00071	0.00102
Spruce Pond Outlet	14/07/82	0.00899	0.01	0.29		
Little Gull Lake Inlet	14/07/82	0.00615				
Little Gull Lake	14/07/82	0.00578	0.01	0.20		
Little Gull Lake Outlet	14/07/82	0.00596				
Mean of all samples		0.00801	$\leq$ 0.01	0.27	0.00077	0.00113

[1]For conversion of P to PO^4, multiply by 3.066.

concentration of 0.77 mg m^{-3} determined by the Canadian Wildlife Service group the waters of the Experimental Ponds Area with pristine, humic waters of Atlantic Canada having low available phosphorus (Kerekes 1983).

Phaeophytin measurements by both Memorial University (Table 10) and the Canadian Wildlife Service (Table 11) tended to be higher than chlorophyll a measurements on corresponding samples. This was likely caused by the constant disruption of sediments and the sampling of decaying material in the shallow lakes.

Nitrogen concentrations measured by Memorial University (Table 10) and the Canadian Wildlife Service (Table 11) were similar in magnitude but those from Memorial University, based on lower detection limits and a greater range of seasonal samples, showed greater variation.

The large differences between total phosphorus and orthophosphate concentrations in the study lakes (Table 10) indicate that most phosphorus in the lakes is in forms not readily available for plant growth. Similarly, the large differences between the inorganic forms of nitrogen and the organic forms indicate that most nitrogen also is not readily available for plant growth. The ratio of average available nitrogen (nitrate, nitrite, and ammonia as N) to average available phosphorus (orthophosphate as P), based on the measurements done by Memorial University, is 10.8[a]. N:P ratios greater than 7 are indicative of limiting phosphorus concentrations (Wetzel 1975). Maintenance of an N:P ratio of 7 would require an average available phosphorus concentration in the study lakes of about 0.0039 ppm[b]. The difference between the measured average concentration of available phosphorus and the calculated average maximum concentration prior to nitrogen limitation is 0.0014 ppm[c]. This corresponds to an average available phosphorus increase of 1.2 kg[d] in Headwater Pond, 0.5 kg[d] in Spruce Pond, and, given similar conditions, 7.5 kg[d] in Little Gull Lake.

(a)

$$\frac{\overline{[\text{Available N}]}\,(\text{ppm})}{\overline{[\text{Available P}]}\,(\text{ppm})} = \frac{\overline{[\text{Nitrate + Nitrite}]}\,(\text{ppm}) + \overline{[\text{Ammonia}]}\,(\text{ppm})}{\overline{[\text{Orthophosphate}]}\,(\text{ppm})}$$

$$= \frac{0.021 \text{ ppm} + 0.006 \text{ ppm}}{0.0075 \text{ ppm } (0.326)}$$

$$= \frac{0.027 \text{ ppm}}{0.0025 \text{ ppm}} = 10.8$$

(b)

$$\frac{\overline{[\text{Available N}]}\,(\text{ppm})}{7} = \frac{0.027}{7} = 0.0039 \text{ ppm}$$

(c)

(b) - $\overline{[\text{Orthophosphate}]}$(ppm) = 0.0039 ppm - 0.0025 ppm = 0.0014 ppm

(d) (c)X lake volume (m^3)

The similarity in average phosphorus, nitrogen, and plant pigment concentrations in both Headwater and Spruce ponds, in spite of their great differences in flushing rates, suggests that the rate of flushing is not differentially regulating average algal biomass in the study lakes. Previously, it was suggested that the inverse relationship of microcrustacean zooplankton density to lake outlet flow in Spruce Pond, not found in Headwater Pond, was a result of the physical removal of zooplankton or their algal food in the faster-flushing, less densely populated, Spruce Pond (Ryan 1984a). Results of the present study support the former of the two hypotheses.

INTERRELATIONSHIPS AMONG SELECTED WATER QUALITY PARAMETERS

Correlations among a number of physical and chemical parameters measured in individual water samples are indicative of both the complexity of interrelationships among measured parameters and the importance of climatic modification of the aquatic habitat of the Experimental Ponds Area.

Of the 28 possible pairings among eight selected parameters, 21 or 75% were statistically significant ($p < 0.05$) as determined by arithmetic (Table 12) and logarithmic (Table 13) correlation analyses. Each parameter was a significant correlate of most other parameters and the strongest correlations were between conductance and chloride ($r = 0.94$), conductance and hardness ($r = 0.64$), calcium and pH ($r = 0.55$), and hardness and chloride ($r = 0.50$). Thus, changes in each parameter tended to be accompanied by changes in most other parameters, indicative of the complexity of interrelationships.

Some climate-related effects are apparent. Water temperature was positively correlated ($p < 0.05$) with pH, alkalinity, and calcium and inversely correlated with turbidity and chloride. Conductance was positively correlated with six of the seven other selected factors and inversely related to temperature, but not significantly so ($p > 0.05$). pH was inversely correlated with chloride and positively correlated with all other factors except hardness.

These trends are indicative of a strong climatic modification of water quality in the study area; particularly during periods of high precipitation and low temperature. During these periods, the typically acidic Newfoundland precipitation (Scruton 1983) would tend to result in greater amounts of acid in the runoff from bogs, depletion of alkalinity, a lowering of pH, and greater turbidity of stream and lake waters. A tendency for the increased deposition of marine aerosols, the main source of Newfoundland's freshwater chlorides (Kerekes and Hartwell 1980; Scruton 1983), during these periods was indicated by the significant ($p < 0.05$) positive relationship between temperature and chloride. These trends would tend to be obscured by varying lag periods between precipitation and runoff events. Such trends could be clarified by water budget modelling coupled with analyses of precipitation and groundwater chemistry.

In spite of the complexities of factor interrelationships, future departures of water quality measurements from conditions encountered in the present study, and future changes in the strength and direction of associations among variables may serve as indicators of long-term environmental change in

Table 12. Arithmetic correlations among selected physical and chemical parameters.

VARIABLE[a]	N	MEAN	STD DEV	SUM	MINIMUM	MAXIMUM
TEMP	529	13.39395085	5.41853243	7085.40000000	0	28.00000000
LAB PH	500	6.32030000	0.30006364	3160.15000000	5.10000000	7.30000000
HARDNESS	500	10.96780000	3.07204298	5483.90000000	1.20000000	40.00000000
CONDUCT	500	34.30680000	19.87980702	17153.40000000	13.00000000	291.60000000
TURBID	500	1.34840000	1.18266429	674.20000000	0.20000000	15.00000000
ALK	500	4.26000000	1.50248958	2130.00000000	1.00000000	11.00000000
CA	500	2.78220000	0.93362008	1391.10000000	0.70000000	5.40000000
CL	500	5.87250000	5.84236812	2936.25000000	2.50000000	77.00000000

CORRELATION COEFFICIENTS / PROB > IRI UNDER HO:RHO=0 / NUMBER OF OBSERVATIONS

	TEMP	LAB PH	HARDNESS	CONDUCT	TURBID	ALK	CA	CL
TEMP	1.00000	0.11642	-0.01306	-0.06724	-0.09288	0.16160	0.06720	-0.12473
	0.0000	0.0101	0.7734	0.1380	0.0403	0.0003	0.1382	0.0058
	529	488	488	488	488	488	488	488
LAB PH	0.11642	1.00000	0.05520	0.02678	0.09868	0.32331	0.55167	-0.10696
	0.0101	0.0000	0.2179	0.5502	0.0274	0.0001	0.0001	0.0167
	488	500	500	500	500	500	500	500
HARDNESS	-0.01306	0.05520	1.00000	0.64041	-0.05767	0.48614	0.25121	0.49592
	0.7734	0.2179	0.0000	0.0001	0.1980	0.0001	0.0001	0.0001
	488	500	500	500	500	500	500	500
CONDUCT	-0.06724	0.02678	0.64041	1.00000	0.07154	0.27264	0.10761	0.93451
	0.1380	0.5502	0.0001	0.0000	0.1101	0.0001	0.0161	0.0001
	488	500	500	500	500	500	500	500
TURBID	-0.09288	0.09868	-0.05767	0.07154	1.00000	0.02697	0.17186	-0.00958
	0.0403	0.0274	0.1980	0.1101	0.0000	0.5473	0.0001	0.8308
	488	500	500	500	500	500	500	500
ALK	0.16160	0.32331	0.48614	0.27264	0.02697	1.00000	0.38763	0.09600
	0.0003	0.0001	0.0001	0.0001	0.5473	0.0000	0.0001	0.0319
	488	500	500	500	500	500	500	500
CA	0.06720	0.55167	0.25121	0.10761	0.17186	0.38763	1.00000	-0.04789
	0.1382	0.0001	0.0001	0.0161	0.0001	0.0001	0.0000	0.2852
	488	500	500	500	500	500	500	500
CL	-0.12473	-0.10696	0.49592	0.93451	-0.00958	0.09600	-0.04789	1.00000
	0.0058	0.0167	0.0001	0.0001	0.8308	0.0319	0.2852	0.0000
	488	500	500	500	500	500	500	500

[a]TEMP = temperature (°C), LAB PH = laboratory pH, HARDNESS = total hardness (ppm), CONDUCT = conductance ($\mu S\ cm^{-1}$ at 25°C), TURBID = turbidity (JTU), ALK = alkalinity (ppm), CA= calcium (ppm), and CL = chloride (ppm).

Table 13. Logarithmic (log_{10}) correlations among selected physical and chemical parameters.

VARIABLE[a]	N	MEAN	STD DEV	SUM	MINIMUM	MAXIMUM
LOGTEMP +1	529	1.10243861	0.26975481	583.19002680	0	1.46239800
LAB PH	500	6.32030000	0.30006364	3160.15000000	5.10000000	7.30000000
LOGHARD	500	1.02272864	0.13137801	511.36432147	0.07918125	1.60205999
LOGCOND	500	1.50798668	0.13226156	753.99333863	1.11394335	2.46478752
LOGTURB +1	500	0.33637158	0.16042566	168.18579165	0.07918125	1.20411998
LOGALK	500	0.60128608	0.16197956	300.64304195	0	1.04139269
LOGCA +1	500	0.56422469	0.10976376	282.11234382	0.23044892	0.80617997
LOGCL	500	0.70947942	0.18521400	354.73970871	0.39794001	1.88649073

CORRELATION COEFFICIENTS / PROB > IRI UNDER HO:RHO=0 / NUMBER OF OBSERVATIONS

	LOGTEMP	LAB PH	LOGHARD	LOGCOND	LOGTURB	LOGALK	LOGCA	LOGCL
LOGTEMP	1.00000	0.12041	-0.03673	-0.06996	-0.04265	0.16440	0.13713	-0.18546
	0.0000	0.0078	0.4182	0.1227	0.3471	0.0003	0.0024	0.0001
	529	488	488	488	488	488	488	488
LAB PH	0.12041	1.00000	0.02120	0.11409	0.14274	0.34901	0.54593	-0.17937
	0.0078	0.0000	0.6363	0.0107	0.0014	0.0001	0.0001	0.0001
	488	500	500	500	500	500	500	500
LOGHARD	-0.03673	0.02120	1.00000	0.52589	-0.02398	0.41479	0.22369	0.23024
	0.4182	0.6363	0.0000	0.0001	0.5928	0.0001	0.0001	0.0001
	488	500	500	500	500	500	500	500
LOGCOND	-0.06996	0.11409	0.52589	1.00000	0.17388	0.43729	0.26654	0.68600
	0.1227	0.0107	0.0001	0.0000	0.0001	0.0001	0.0001	0.0001
	488	500	500	500	500	500	500	500
LOGTURB	-0.04265	0.14274	-0.02398	0.17388	1.00000	0.02481	0.24264	0.05594
	0.3471	0.0014	0.5928	0.0001	0.0000	0.5799	0.0001	0.2118
	488	500	500	500	500	500	500	500
LOGALK	0.16440	0.34901	0.41479	0.43729	0.02481	1.00000	0.39005	0.09905
	0.0003	0.0001	0.0001	0.0001	0.5799	0.0000	0.0001	0.0268
	488	500	500	500	500	500	500	500
LOGCA	0.13713	0.54593	0.22369	0.26654	0.24264	0.39005	1.00000	-0.05527
	0.0024	0.0001	0.0001	0.0001	0.0001	0.0001	0.0000	0.2173
	488	500	500	500	500	500	500	500
LOGCL	-0.18546	-0.17937	0.23024	0.68600	0.05594	0.09905	-0.05527	1.00000
	0.0001	0.0001	0.0001	0.0001	0.2118	0.0268	0.2173	0.0000
	488	500	500	500	500	500	500	500

[a]One was added to each value of those variables having values of less than one. Variables are ordered as in Table 12.

the study area. In addition, as a result of the similarity of the water quality of the Experimental Ponds Area to the average water quality recorded from other Newfoundland waters (Jamieson 1974; Scruton 1983), water quality measurements in the Experimental Ponds Area may serve as comparative data for other waters including those subjected to experimental manipulation or other forms of environmental change.

SUMMARY

1. Physical and chemical limnological data were obtained from the Experimental Ponds Area from 1977 to 1982 for the purposes of:

   - documenting natural variation in the Area prior to a possible experimental manipulation of part or all of the Area;
   - documenting natural variation in the freshwaters of Newfoundland; and
   - predicting the abundance of life forms in Newfoundland's fresh waters.

2. The Experimental Ponds Area includes three small brown-water lakes and their tributary streams at the headwaters of the Gander River system, central Newfoundland. The three lakes are, from upstream to downstream, Headwater Pond, Spruce Pond, and Little Gull Lake.

3. The Experimental Ponds Area lies in a predominantly black spruce forest with Sphagnum bogs. Logging operations took place in part of the Area from 1979 to 1982 and forest insecticide was sprayed about 13 km south of the Area in 1977 and 1978. Human habitation in the Area consists of two small cottages on Spruce Pond. The waters upstream of Spruce Pond's outlet at Little Gull Lake were closed to angling in 1981.

4. Apart from morphometric data, most measured parameters were monitored on the lakes and their tributaries at approximate two week intervals from near the end of May to early October, starting in 1977 on Spruce Pond and in 1979 in Headwater Pond. Some additional samples were obtained from these waters and samples from Little Gull Lake were taken, as time permitted, starting in 1978.

5. Headwater Pond has a water surface area of 76.1 ha, a volume of 871,767 m^3, a mean depth of 1.1 m, and a maximum depth of 3.3 m. It flushes about 6.2 times yr^{-1} and is comprised of two basins of similar size.

6. Spruce Pond, downstream of Headwater Pond, has a water surface area of 36.5 ha, a volume of 364,282 m^3, a mean depth of 1.0 m, and a maximum depth of 2.1 m. It flushes about 49.7 times yr^{-1} on downstream to Little Gull Lake.

7. Little Gull Lake has a water surface area of 306.5 ha, a volume of 5,327,517 m^{-3}, a mean depth of 1.7 m, and a maximum depth of 6.3 m. It flushes about 11.0 times yr^{-1}.

8. Changes in recorded lake water levels correspond to about 15% of the volume of Headwater Pond and about 35% of the volume of Spruce Pond. Maximum recorded ice thickness was 61 cm.

9. Lake substrates range from mud and humic silt to detritus, rubble, boulders, and bedrock. Stream substrates are predominantly boulders with little salmonid spawning habitat in comparison to downstream areas.

10. Measured stream temperatures ranged from 0.0 to 28.0°C while lake temperatures ranged from 0.0 to 23.0°C. Average weekly mean mid-day lake water temperatures from May to October each year ranged from 10.6 to 15.1°C.

11. Stream velocities and rates of flow measured at Spruce Pond's outlet from May to October, 1978 to 1982, ranged from 0.00 to 0.71 m sec^{-1} and 0.00 to 1.76 m^3 sec^{-1}. The average May to October flow tended to be greater in those years when the average May to October temperature was low and the average May to October precipitation at Grand Falls was high.

12. A Secchi disc was always visible on the bottom at sample stations on Headwater and Spruce ponds. The average Secchi depth on Little Gull Lake was 3.2 m. The mean turbidity of water samples taken throughout the Area was 1.4 J.T.U and water color, measured as part on an independent study, ranged from 35 to 180 H.U.

13. No forest insecticide, sprayed near the Area in 1977 and 1978, was detected in water samples taken from the Experimental Ponds Area.

14. Dissolved oxygen concentrations throughout the study area ranged from 7 to 13 ppm, including those from under-the-ice winter samples.

15. The pH of the waters of the Experimental Ponds Area, measured in the laboratory, ranged from 5.1 to 7.3 with a mean of 6.3. Seasonal fluctuations in pH exhibited no consistent pattern from year to year and average annual pH did not exhibit a consistent increase or decrease from 1977 to 1982.

16. The specific conductance of the waters of the study area ranged from 13.0 to 291.6 μ S cm^{-1} with a mean of 34.3 μ S cm^{-1}.

17. Chloride concentrations in the study area ranged from 2.5 to 77.0 ppm with a mean of 5.9 ppm.

18. Total hardness in the study area ranged from 1 to 40 ppm with a mean of 11 ppm. Calcium concentrations were 0.7 to 5.4 ppm with a mean of 2.8 ppm. The mean calcium to magnesium ratio was 1.8.

19. Total alkalinity measurements ranged from 1.0 to 11.0 ppm with a mean of 4.3 ppm and indicate that the waters of the Experimental Ponds Area are typically of moderate sensitivity to acidification but vary from extremely sensitive to low in sensitivity.

20. Total phosphorus concentrations, measured in July and August samples taken from streams and lakes in 1982, ranged from 5.8 to 11.9 mg P m^{-3} with a mean of 8.0 mg P m^{-3}. Chlorophyll a measurements from lake water samples in August of 1982 averaged 0.77 mg m^{-3} and, together with total phosphorus measurements, group the study lakes with pristine, humic waters of Atlantic Canada having low available phosphorus. Total filtrable phosphorus measurements on lake water samples from May to October of 1982 ranged from 2.0 to 47.9 mg P m^{-3} with a mean of 6.9 mg P m^{-3}.

21. The calculated ratio of average available nitrogen (nitrate, nitrite, and ammonia) to average available phosphorus (orthophosphate) was 10.8; indicative of phosphorus limitation in the waters of the study area.

22. Correlations among eight selected physical and chemical parameters indicated that changes in each parameter tended to be accompanied by changes in most other parameters and were indicative of a strong climatic modification of water quality in the study area.

23. Future departures of water quality measurements from conditions encountered in the present study and future changes in the strength and direction of associations among variables may serve as indicators of long-term environmental change in the study area.

24. Overall, the physical and chemical characteristics of the waters of the Experimental Ponds Area are typical of the freshwaters of insular Newfoundland. Water quality measurements from the Experimental Ponds Area may serve as comparative data for other waters including those subjected to experimental manipulation or other forms of environmental change.

ACKNOWLEDGMENTS

A large number of people contributed advice, comment, criticism, time, and labor towards this part of the study of the Experimental Ponds Area. The following assisted in a major way.

Sampling was initiated in 1977 by C. Morry.

L. J. Cole and D. P. Riche provided technical assistance with the bulk of the measuring, sampling, and water quality analyses.

R. Benson determined calcium concentrations in samples from 1981 and 1982.

M. Hooper and other staff of Memorial University's Water Analysis Facility, under contract, measured phosphorus, nitrogen, and plant pigment concentrations in samples from 1981 and 1982.

G. Howell and J. Kerekes of the Canadian Wildlife Service provided measurements of phosphorus, nitrogen, and plant pigments from 1982 samples.

A. Chaytor and R. J. Tucker assisted with the computer storage of data.

G. Marshall and G. Somerton assisted with statistical analyses.

G. King, H. Mullett, and, under contract, Technograph Ltd. assisted with figure reproduction.

M. Bursey and K. Harding typed the report.

M. F. O'Connell, T. R. Porter, and D. A. Scruton constructively reviewed the manuscript.

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POOR

QUALITY

ORIGINAL